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TAMARISK CONTROL IN SOUTHWESTERN UNITED STATES

PROCEEDINGS OF TAMARISK CONFERENCE
UNIVERSITY OF ARIZONA
TUCSON, ARIZONA
SEPTEMBER 2 AND 3, 1987

Special Report No. 9
Cooperative National Park Resources Studies Unit

Technical Coordinators

Michael R. Kunzmann
R. Roy Johnson
Peter S. Bennett

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National Park Service

COOPERATIVE NATIONAL PARK RESOURCES STUDIES UNIT
University of Arizona/Tucson - National Park Service

The Cooperative National Park Resources Studies Unit/University of Arizona (CPSU/UA) was established August 16, 1973. The unit is funded by the National Park Service and reports to the Western Regional Office, San Francisco; it is located on the campus of the University of Arizona and reports also to the Office of the Vice-President for Research. Administrative assistance is provided by the Western Archeological and Conservation Center, the School of Renewable Natural Resources, and the Department of Ecology and Evolutionary Biology. The unit's professional personnel hold adjunct faculty and/or research associate appointments with the University. The Materials and Ecological Testing Laboratory is maintained at the Western Archeological and Conservation Center, 1415 N. 6th Ave., Tucson, Arizona 85705.

The CPSU/UA provides a multidisciplinary approach to studies in the natural and cultural sciences. Funded projects identified by park management are investigated by National Park Service and university researchers under the coordination of the Unit Leader. Unit members also cooperate with researchers involved in projects funded by non-National Park Service sources in order to obtain scientific information on Park Service lands.

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Sponsored by

Cooperative National Park Resources Studies Unit

September 1989

National Park Service
Cooperative National Park Resources Studies Unit
School of Renewable Natural Resources
University of Arizona
Tucson, AZ 85721

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Any meeting of this size and scope owes its success to a large number of individuals and organizations. First, we would like to thank the Washington Office (WASO), the Western Regional Office (WRO) and the Southwest Regional Office (SWRO) of the National Park Service (NPS) whose financial support and encouragement helped make the conference a reality.

We are especially grateful to those who presided over the various conference sessions and to those individuals who donated their time to provide logistical support. We would also like to thank the special efforts made by the staff at the Western Archeological and Conservation Center to accommodate this conference in their facility.

Finally, we would like to thank all the speakers and the NPS resource management specialists who found the additional time to contribute papers for this proceedings.

Michael R. Kunzmann
R. Roy Johnson
Peter S. Bennett

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PROCEEDINGS DEDICATION

Thomas M. Gavin, Western Regional Forester
Mietek C. Kolipinski, Western Regional Ecologist

This volume is dedicated to Francis H. Jacot. One of the foremost natural resources management specialists in the National Park Service, he died on September 2, 1987, surrounded by loved ones in California.

He contributed much to the National Park Service. "Jake" began his career in July 1946 as a Blister Rust Control Worker in Yosemite National Park. After receiving his B.S. degree in Wildlife Management from Humboldt State University, he returned to the National Park Service as a Rust Control Crew Leader and continued to work in this capacity until his enlistment in the U.S. Navy in July 1950. The next four years of his life were devoted to country with his participation in the Korean War. Later Jake was reemployed by the National Park Service as a seasonal park ranger at Lake Mead National Recreation Area. In 1957, while working as a seasonal at Organ Pipe Cactus National Monument, Jake received his first career conditional appointment as a Park Ranger at Lake Mead.

In September 1958, he was reassigned to Glacier Bay National Park, where he was later promoted to chief park ranger. Francis Jacot was reassigned as supervisory park ranger (asst. chief) at Crater Lake, where he received career status in September 1960. Two years later he was promoted to WASO staff biologist, and in October 1964, to WASO staff park ranger. In 1967, he returned to Lake Mead as an assistant chief park ranger and remained in this position until he joined the WRO staff, initially as a resources program specialist. The next ten years of service at WRO saw Jake reassigned to staff park ranger and ultimately to Chief, Division of Natural Resources Management. Finally, he returned to Lake Mead National Recreation Area in 1986, to serve as assistant superintendent until his retirement later that year.

Jake was perhaps most well-known for his willingness to take on controversial and sensitive issues, always siding with the threatened resource. Indeed, no battle was ever too large for this man, and he was a master at evaluating the politics of the situation. The reestablishment of a tule elk herd at Point Reyes and the removal of 15,000 feral goats from Hawaii Volcanoes National Park and 8,000 feral burros from Grand Canyon National Park and Death Valley National Monument are typical of Jake's ability to meet the "road blocks" head-on and, in the end, prevail in a manner consistent with the mission of National Park Service. Incidentally, he successfully urged staffs of

Francis H. Jacot 1929 - 1987

appropriate Western Region parks to start saltcedar control programs and not to give up on this difficult task.

These proceedings, in large part, are a testimony to his efforts. For years, Jake served as "Western Regional Encyclopedia" on issues pertaining to ecosystem management. His extensive knowledge of natural resources and operations of all area parks provided continuity and integrity to regional programs. Jake led an aggressive campaign, promoting the wise use of prescribed fire/prescription natural fire for accomplishing natural resource management objectives; his early direction and future visions in this area of management provided the foundation for a program that today enjoys standardization and professionalism warranted by such programs. Jake's years of experience as a ranger allowed him a unique authority and opportunity to preach a balanced approach to ranger activities, interpretation, and natural resource management. Many of the natural resource management positions and/or divisions which exist throughout the Western Region today can be traced back to initiatives taken by Jake. In addition, Jake was one of the principal advocates for the creation of the Servicewide natural resources trainee program. When this program was threatened, he defended its importance and the need for its continuation. Jake's obsession for improving the professionalism of the Servicewide natural resource management program put him at the fore-front of efforts to adopt the 401 series as a specific natural resource management specialist series. Additionally, some unique natural resource management funding mechanisms that are alive and well within the Western Region (rotating resource base, cyclic maintenance program) were created after Jake had laid down the foundation for such programs.

There was yet another aspect of Jake, the person, that brought him uniform respect among his peers--his sensitivity and compassion for others. Jake was loved by his staff, all of whom benefitted at one time or another from his friendship. When others were in need, Jake gave generously of his time and resources.

In 1986, Jake made his last NPS public appearance in front of the Western Regional Natural Resources Management Workshop at Las Vegas. As keynote speaker, he fought back emotion as he reflected on his 34 years of NPS service and, more specifically, on the evolution of natural resource management throughout those years. His presentation was acknowledged by the 100 plus natural resource managers present in the form of a sustained, standing ovation. Most fitting, Western Regional Director Stan Albright referred to Francis Jacot as a "legend in his own time" ...a man of the highest standards and principles, never settling for anything less than the best for our national parks.

INTRODUCTION

Michael R. Kunzmann, Research Management Specialist
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These proceedings contain the results of a saltcedar conference that was organized by the Cooperative National Park Resources Studies Unit/University of Arizona (CPSU/UA), and held at the Western Archeological and Conservation Center in Tucson, Arizona, on September 2 and 3, 1987. This conference was the third of three planning meetings held in Tucson, to discuss research and resource management efforts with this important plant. Papers, discussions, and workshops at the September meeting were presented by 30 representatives from 5 different state and federal organizations: National Park Service (NPS), Fish and Wildlife Service, Agricultural Research Service, Northern Arizona University, and University of Arizona (Figure 1). The conference was attended by representatives of more than 15 NPS offices or areas including Western, Southwest, and Rocky Mountain regions as well as the Washington Office. Other agencies represented at previous meetings included U.S. Geological Survey and University of Nevada at Las Vegas.

The September meeting was part of an NPS saltcedar research and management program. During 1987, with the assistance of the Washington Office (WASO), the Western Regional Office (WRO) and the Southwest Regional Office (SWRO) of the NPS embarked on a task force effort to examine the impacts of saltcedar on ecosystem processes in national park areas of the Southwest. As part of this task force effort a series of interregional, interagency meetings were designed to bring together scientists, resource management specialists, interpreters, and managers to discuss the saltcedar issue in the Southwest. Additional efforts included saltcedar inventories for several park areas and field control activities with scientifically designed programs, including follow-up monitoring for control success data.

Saltcedar (*Tamarix ramosissima*) is one of the most widely distributed and troublesome weeds along watercourses in park lands of the Southwest. The name saltcedar is used for several species of tamarisk, all belonging to the old world genus *Tamarix*, in the family Tamaricaceae. The most recent monograph for the genus (Baum 1978) lists 54 species of shrubs, subtrees, and trees. Some experts think that Baum (1978) has split the genus into too many species and that only a small fraction of the 54 "taxa" are valid

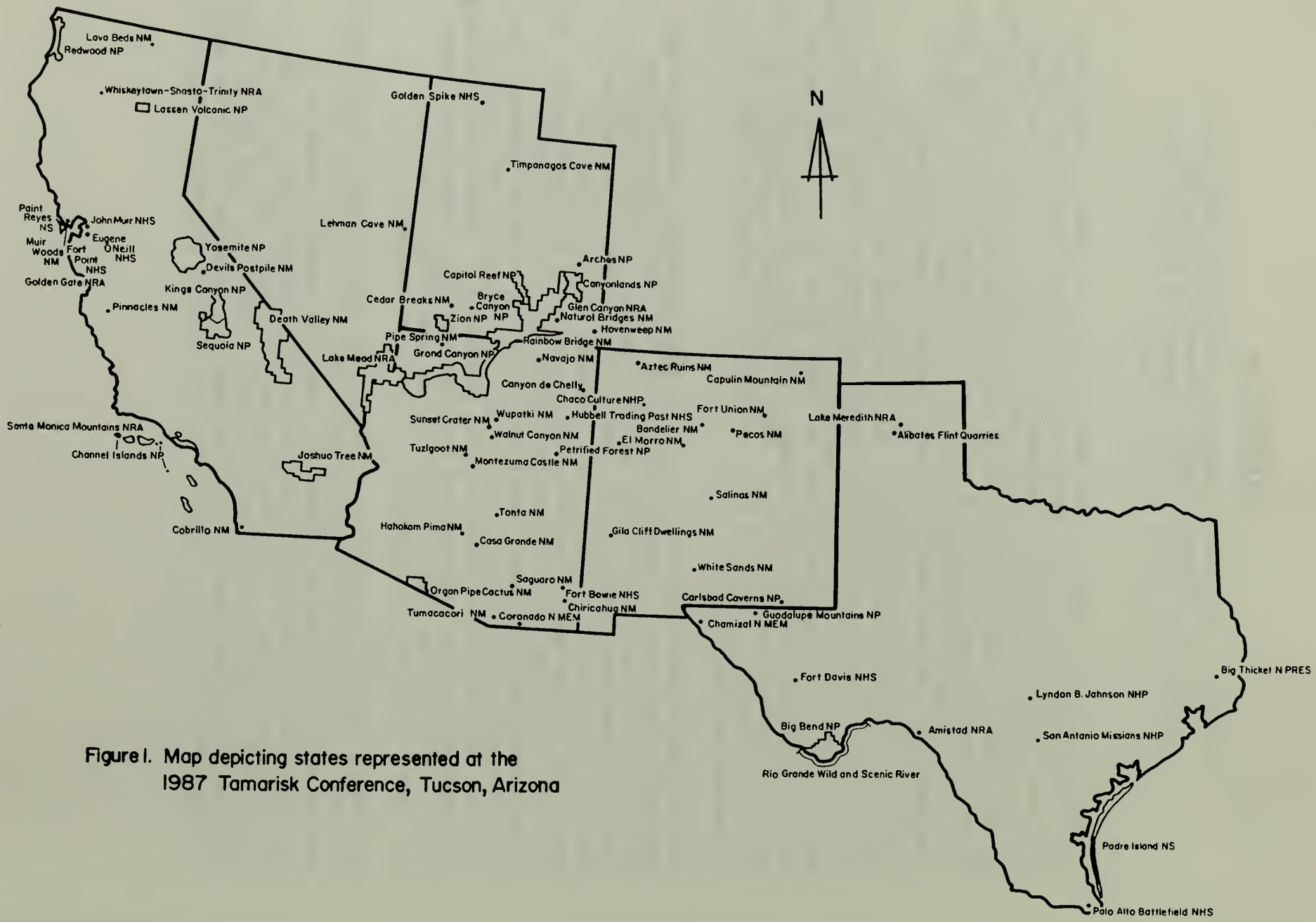

Figure 1. Map depicting states represented at the 1987 Tamarisk Conference, Tucson, Arizona

species (Larry Stevens, Dept. Biology, N. Ariz. Univ., pers. comm.). Several taxa ("species") of *Tamarix* have been introduced into the United States since the early 1800s (Robinson 1958). The first were apparently introduced by nurserymen and most tamarisk have been planted as ornamentals, windbreaks, or for stabilizing streambanks. It was the latter practice and the ability of saltcedar to spread rapidly from seeds that allowed at least one species to become naturalized and to become widely established as a troublesome, pest species. Christensen (1962) found that tamarisk was not recorded from about 1869 to 1875 by early explorers of the Green and Colorado rivers. Meinzer (1923) did not discuss saltcedar in the Southwest in his landmark paper that, among other things, coined the word "phreatophyte" (pump plants), a term widely used today for saltcedar. Its noticeable establishment and spread along southwestern watercourses was apparently after the 1920s. Since then it has spread rapidly along streams and even along ephemeral watercourses, roadsides, and other habitats that receive higher than normal surface and/or subsurface water.

The taxonomic affinities of these naturalized plants have been widely discussed (Horton 1977, Kerpez and Smith 1987). They have been variously referred to as *Tamarix pentandra*, *T. chinensis*, and most recently as *T. ramosissima*. Speculation suggests that these stands of saltcedar in the Southwest may be comprised of more than one species or even consist of a hybrid swarm, benefitting from the advantages of hybrid vigor in their continuing spread into new areas. Although most *Tamarix* are shrubs, one of these introduced species, athel (*T. aphylla*), is a tree. Scattered, generally small populations of naturalized athel currently constitute little threat to maintenance of native ecosystems and associated processes.

Saltcedar has not become a major problem along colder, high elevation and northern streams. Specimens from Canada are relatively few, consisting of three species (Baum 1967). The senior author has never noted *Tamarix* during several trips to southern Canada, including the collection areas mentioned by Baum. On the other hand, tamarisk species generally grow rapidly in the warmer climate of the semiarid southwestern United States, northern Mexico, and possibly further south, reaching their best development along major lowland watercourses, such as the Colorado River and Rio Grande and many of their tributaries, e.g., the Pecos and Salt rivers. Because of the large number of NPS areas along these drainages the reported wildlife and recreational impacts resulting from this invasive species have widespread management implications. In some areas naturalized saltcedar threatens native plant and animal communities, interfering with native ecosystem processes. Johnson and Carothers (1987) have proposed using the terms "naturalized" and "exotic" for entire ecosystems rather that at the species level, as these terms have been commonly used in the past. They define

the two terms as follows: a Naturalized Ecosystem contains biotic communities with both indigenous and nonnative plants and/or animals; in these communities dominance or predominance is not a function of species origin (that is, native or nonnative), and the indigenous biota is not threatened either in species richness or population sizes by nonnative species. In naturalized ecosystems biotic and abiotic process have either reached or are evolving toward an equilibrium in which exotics do not restrict or interfere with native organisms or ecological processes, rather than evolving toward the destruction of components and processes of the original, natural ecosystem. If indigenous community components or native ecosystem processes are threatened by nonnative species the term Exotic Ecosystem is more appropriate.

Reports in these proceedings document the magnitude of the saltcedar problem faced by managers of natural resources in the American Southwest. Problems reported in literature include high water use through evapotranspiration (van Hylckama 1980), physical impediment of streamflow, exacerbating flooding during high flows (Robinson 1965); replacement of native riparian vegetation or growth in areas where little to no woody native vegetation grows (Turner 1974) and low wildlife usage (Anderson et al. 1979). Saltcedar has been especially successful in becoming established and out-competing native riparian vegetation along stretches of streams where modified flow regimes result from construction of dams and other water diversion projects (Everitt 1980, Kerpez and Smith 1987).

In spite of the negative factors presented in the literature for saltcedar, numerous reported positive factors need to be addressed in any complete analysis of the problem. It is valued by beekeepers as a honey-producing plant (Pellett 1976, Horton and Campbell 1974). Brown and Johnson (these proceedings) provide a look at saltcedar as habitat for native riparian birds. Its importance to nesting mourning doves (*Zenadura macroura*) and white-winged doves (*Z. asiatica*), the two most important upland game birds for much of the Southwest, has long been recognized (Wigal 1973). Its value as habitat for other species of birds has been documented by Brown (1989) for the Colorado River in Grand Canyon National Park and avian use has been discussed further by Hunter et al. (1985) for other southwestern rivers with mixed results, depending on the river. Others have discussed the use of saltcedar by recreationists for shelter, e.g., by hikers and whitewater rafters along the Colorado River in Grand Canyon (Johnson and Carothers 1982, 1987).

An important factor in managing saltcedar in NPS areas is its nonnative status and NPS policy regarding maintaining native organisms and perpetuation of natural processes. Saltcedar is considered enough of a threat to management and maintenance of natural ecosystems and processes that large amounts of effort are expended in its control and attempted eradication, at least in

some areas. In the past, a major concern about control programs has been possible deleterious impacts on native ecosystem components associated with saltcedar, especially with use of chemicals. On the other hand, control alone may not be sufficient. Numerous projects have experimented with revegetating riparian habitats with native species (Anderson et al. 1979); a procedure that may need to be used in conjunction with chemical, mechanical, or biological control to return many of our disturbed ecosystems to nearly natural conditions.

The papers in these proceedings discuss the means by which the NPS saltcedar task force is applying saltcedar inventories, scientific examination, experimentation, control methods, and monitoring to this important program. This publication should not be considered the end of the program but a summary of the program to date. Attempts are currently underway to secure funding and personnel to further the program. This effort includes the possibility of cooperative programs with the Bureau of Reclamation in methods of reducing the saltcedar problem along reaches of watercourses under their jurisdiction as well as with Agricultural Research Service in examining the possibilities of biological control.

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Papers Presented by Parks at the Tamarisk Conference

1987 TAMARISK CONTROL PROJECT: PETRIFIED FOREST NATIONAL PARK

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Petrified Forest National Park, AZ 86028

ABSTRACT

During the summer of 1987, Youth Conservation Corp. crews were used to cut tamarisk plants (*Tamarix ramosissima*) in Petrified Forest National Park. The cut stumps were immediately treated with the herbicide Garlon 3A. A preliminary check of the control area approximately six weeks later revealed a 21% kill rate in the treated plants. This figure is below what was expected, due to the herbicide used, dry season application, and technique. Preliminary findings indicate that plant size and water stress, and not neighboring plants, were the primary determinants in tamarisk death. From the experience of this summer, plans are being made for a more effective control program next spring.

Petrified Forest National Park is located in northeast Arizona, about 120 miles east of Flagstaff, Arizona (Figure 1). The park is characterized by rolling, grassy plains broken by large areas of rugged badlands making up the Painted Desert. The park was initially established as a national monument by Presidential Proclamation in 1906 to preserve the fossil remains of Mesozoic forests. In 1932 a large area of the Painted Desert was added to the monument, and national park status was achieved in 1962.

Although established primarily to preserve the fossil remains typified by the petrified logs and bones which abound in the badlands areas, numerous other significant resources are preserved in the park, including scenic, archeological, and ecologic values. The park's vegetation is a composite of Great Basin desert scrub and short-grass prairie types. In the late 1800s, widespread destruction of natural plant communities of the region resulted from overgrazing, drought, and floods. The region as a whole has never recovered (Miller et al. 1977). However, elimination of grazing within Petrified Forest, beginning in 1934 (Walker 1937b) and completed in 1962, has allowed a dramatic recovery in the park's vegetation. Early American explorers in the region do not provide very complete records of vegetation in the area (Foreman 1941, Sitgreaves 1853), so the true pre-Columbian nature of the vegetation cannot be determined. However, Miller et al. (1977) do refer to the Petrified Forest as "the last undisturbed short-grass prairie in Arizona."

Tamarisk is an exotic shrub that has become widely established in the southwestern United States. Because of its exotic status, it has been the target of eradication efforts for years. In Petrified Forest National Park, tamarisk was first recorded growing along the Puerco River in 1937 (Walker 1937a), although it had been planted in the region as early as 1909 (Hereford 1984). The taxonomy of the tamarisk found in the park is still undetermined. Originally assigned to *Tamarix pentandra* (Kierstead 1981), it seems likely the plant is actually *T. ramosissima*. Control of the plant has been attempted in the past through excavation, cutting, and herbicide use, but with mixed results (Johnson 1985). This year's control efforts were based on the exotic status of tamarisk, the intrusion the plant offers in the park's grassland environment, and the desire to experiment with control techniques.

Beginning on June 10, 1987, a Youth Conservation Corps (YCC) crew, under the supervision of a park ranger, began tamarisk control along the East Fork Dry Wash drainage in the central part of the park. Delay of the monsoon rains allowed control work to continue through July 22. Plants were cut using bank blades, loppers, and chainsaws. Following the initial reduction of the plant, final cuts were made to the stems, which were then immediately painted with undiluted Garlon 3A. Stumps were marked with flagging, and daily log sheets were maintained. Slash was piled in the wash, and most piles were burned to reduce seed spread.

Concurrent with the control efforts, and working ahead of the cutting crews, line transects were made of uncut tamarisk and surrounding vegetation. The transects were 16 feet (5 meters) long oriented perpendicular to the wash-bed along which the tamarisk was growing. Approximately 1 plant in 10 was measured ("plants" in small thickets were counted by canopy breaks). Transects were staked, and plant species and location along the transect were recorded. The transects will provide long-term information on the response of the tamarisk and other plants to the control efforts.

A follow-up check of the control areas was done August 28-30. The condition of 338 clumps of tamarisk were recorded with respect to regrowth, vigor, location, and size. The condition of seven other selected species surrounding the tamarisk was also recorded. It was determined that 21% of the treated tamarisk had died. An additional 15% had resprouted but appeared weak. Good regrowth was seen in 39% of the clumps, and vigorous regrowth (including some blooming specimens) was seen in 25%.

It appears that tamarisk mortality was related to size of the plant and location of growth with respect to the washes. Large tamarisk proved more resistant than small ones, perhaps due to a

greater biological "reserve" with which to counter the herbicide. Large clumps also tended to have numerous stems, some of which may have been overlooked in treatment. Small plants, with smaller reserves and fewer stems, probably received more herbicide in relation to their size, and a more complete coverage of stems issuing from a single crown.

Plants growing adjacent to washes displayed a greater resistance to the herbicide than those growing further back in the floodplain or along abandoned meanders. These upland plants were probably under a greater water stress, and required less of an upset to kill them. It also seems likely that flood conditions in a wash environment encourage development of a larger root system to allow the plant to withstand flooding (William M. Neill, per. comm. 1987).

During the August survey, the condition of seven species growing around the tamarisk was also recorded. The purpose of this part of the survey was two-fold. First, surrounding vegetation was observed to determine any ill effects from the control efforts. Second, it was hoped that some vegetation types may inhibit the regrowth of the tamarisk itself after treatment.

Nontarget effects of tamarisk control can be divided into three categories: herbicide poisoning, trampling, and loss of shade. Herbicide poisoning was probably the least important of the three. Four of the surrounding species checked were grasses, which are not susceptible to Garlon 3A (wheatgrass [*Agropyron smithii*], Indian ricegrass [*Oryzopsis hymenoides*], Johnson grass [*Sorghum halepense*], and Alkalai Sacaton [*Sporobolus airoides*]). Of the broad-leaved plants checked, one (Indian paintbrush [*Castelleja linariaefolia*]) is a root parasite, the other two (rubber rabbitbrush [*Chrysothamnus nauseosus*], and dunebroom [*Parryella filifolia*]) were not. Only 2% of the nonparasitic *C. nauseosus* and none of the *P. filifolia* were found dead, but 59% of the parasitic *C. linariaefolia* were killed. Thus, it appears that the herbicide stayed on target in the tamarisk and spread only to its parasites.

Trampling was probably the largest negative factor for surrounding vegetation during tamarisk control. Because of the arid climate and control efforts during the dry season, plants were dry and brittle. Attacking the tamarisk often resulted in trampling and breaking surrounding growth. However, regrowth (after the rainy season) is taking place.

Loss of shade provided by the tamarisk was probably responsible for much of the wilt and/or browning seen on plants near the tamarisk stumps. That this is a shading effect is evidenced by brown tops and green bottoms on the plants, since poisoning should show the reverse. From the qualitative data collected, it appears that nearby plants do not affect the susceptibility of

tamarisk to poisoning. The greatest effect seems to be from the parasitic *C. linariaefolia*. It is possible that the energy drain imposed on the tamarisk supporting the parasite could weaken the plant and make it more susceptible to herbicide poisoning. However, tamarisk killed in this summer's control program had only 55 more *C. linariaefolia* than treated tamarisk in general, a figure that is probably not statistically significant.

The low kill rate experienced this summer at Petrified Forest is probably due to a number of causes. Of course, it was hoped that 100% of the tamarisk would be killed, but only 21% were. One possibility is the pesticide used. Garlon 3A was selected on the basis of past use in the park, in which a 76% kill rate was obtained (Johnson 1985). However, in talking with Dow Chemical, only a 42% kill rate should be expected using Garlon 3A on stump cuts of tamarisk (they report 100% for Tordon RTU undiluted, and 100% for Garlon 4 diluted 1 Garlon: 2 water). Thus, it appears that the effectiveness of Garlon 3A on tamarisk is uncertain.

Another factor in reducing the kill rate was the time of application. To utilize YCC crews, control work was done in the early summer. Unfortunately, this is the hottest, driest time of the year, and plants may be dormant waiting for the summer rains to start in July. The Garlon itself, a water soluble mix, could have evaporated quickly after stump application. Thus, herbicide uptake may have been low, reducing effectiveness.

Technique also may have played a major role in reducing effectiveness. Tools used in the control effort often resulted in stumps that were 20-30 cm. tall, rather than cut at ground level. Although treated, these stems represent additional biomass to dilute the poison, and many such stumps have resprouted. The practice of reducing the tamarisk prior to making the final cut and applying the herbicide may have also allowed the plant to begin disengaging from a particular shoot before the pesticide was applied, again lowering absorption.

To correct these problems, plans are already being made for next year's control work on tamarisk at Petrified Forest. Future work could be done using a different herbicide (perhaps Garlon 4 or Tordon), which may provide better control. However, since the Garlon has a short half-life (approximately 30 days according to Dow), it does not spread to adjacent vegetation. It is also nonrestricted, and other studies have shown much higher kill rates than those seen at Petrified Forest in 1987. Therefore, Garlon 3A will be used in conjunction with the following improvements to try to obtain a high kill rate. Work will be done in the spring or fall, when plants are actively growing. Most important, better tools will be used, to allow cutting right at ground level, thus reducing the possibilities for resprouting.

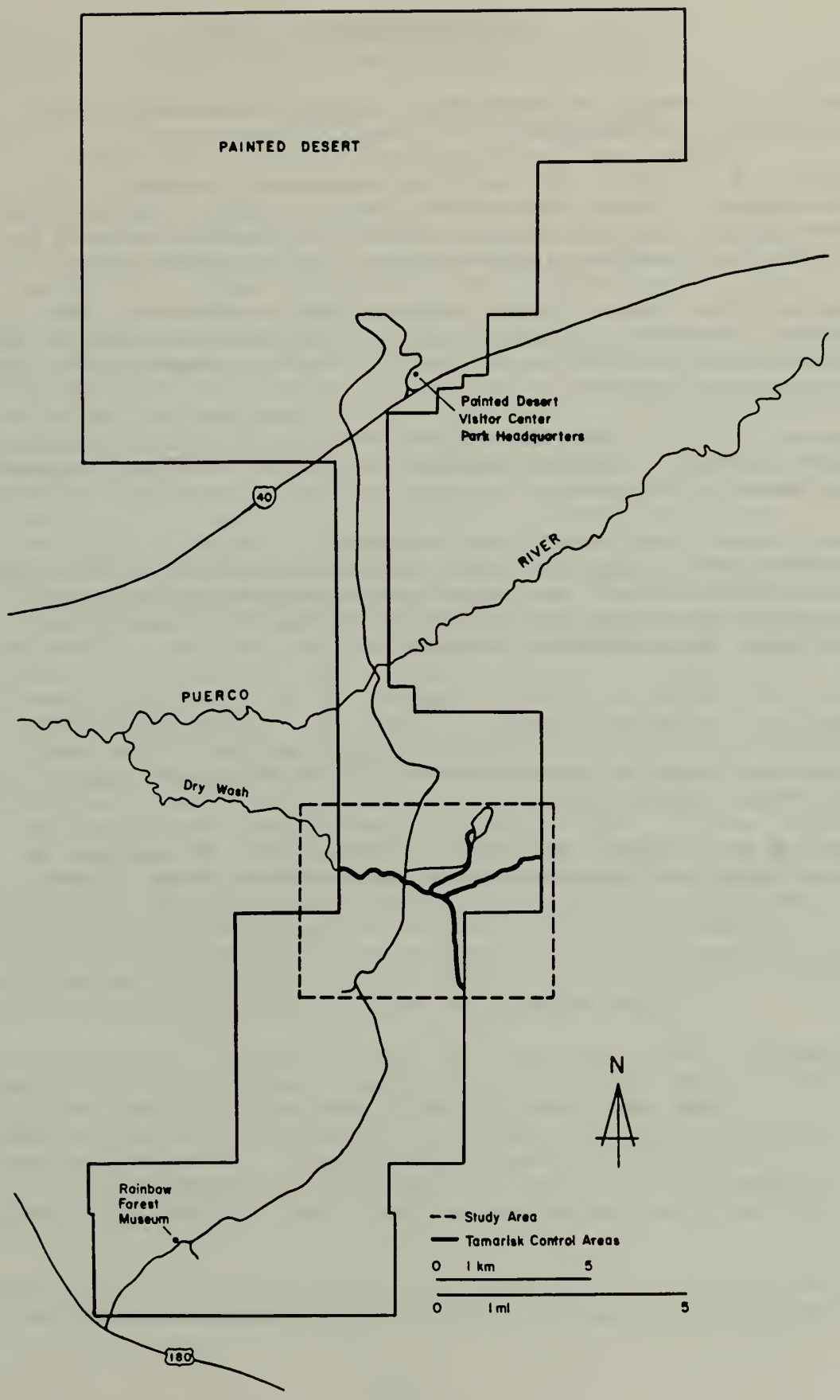

Figure 1. TAMARISK CONTROL PROJECT
PETRIFIED FOREST NATIONAL PARK

Lois A. Kain

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TAMARISK AND ITS CONTROL AT LAKE MEAD NATIONAL RECREATION AREA

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Lake Mead National Recreation Area is located in southern Nevada and northwestern Arizona. It encompasses Lake Mead (163,000 surface acres) and Lake Mohave (29,000 surface acres), both formed by the impoundment of the Colorado River. The total acreage of the recreation area covers 1.5 million acres of land and water. The National Park Service began administration of Lake Mead National Recreation Area under a cooperative agreement with the Bureau of Reclamation in 1936. Both Lake Mead and Lake Mojave were formed as a result of the construction of hydroelectric projects at Hoover and Davis dams. With 180 miles of waterways, the area provides a broad variety of water-related sports and recreational opportunities. Numerous park and concession facilities offer services and sites for boating, lodging and food, swimming, camping, and fishing. Lake Mead also is a unique place to explore the transition zone of the Colorado Plateau to the east and the Basin and Range provinces to the north and west. Species from the Sonoran, Mohave, and Great Basin deserts can be found here and the area is rich in geologic diversity.

Tamarisk has been invading the shorelines of Lake Mead since 1941 and Lake Mohave since 1953. Approximately 95% of the springs in the recreation area also have tamarisk growing around them. Four control projects have been undertaken since 1975. These include control at springs in the Newberry Mountains by the cut and treat method, removal by bulldozer along the shoreline at Telephone Cove (Arizona), removal from test plots using four different methods along the shoreline near Willow Beach, and removal from a beach area near Cottonwood Cove in 1986. Future removal efforts will be directed at springs critical for wildlife and at selected shoreline beaches preferred by the recreating public.

The lake completely filled in 1941 at elevation 1220 feet MSL then reached a low in 1964 of elevation 1099 feet MSL. Tamarisk has thus been invading the shoreline of Lake Mead since approximately 1941. Lake Mohave was created in 1953 with the completion of Davis Dam. Tamarisk has been invading the shoreline of Lake Mohave for the past 34 years. Lake Mohave fluctuates on an annual basis from approximate elevation 629 feet to 647 feet MSL.

From looking at old photographs it is known that tamarisk was growing along the Colorado River before the building of Hoover

Dam. As the two lakes were created, tamarisk encroached on the shorelines which were part of the creosote/bursage or desert wash communities. Invasion of springs in the recreation area by tamarisk was not documented until a survey was completed in 1974, which identified tamarisk existing at approximately 95% of the springs in the park.

Little documentation of tamarisk invasion was made until the 1974 spring inventory. Old photographs available from the park naturalist collection are about the only reference to determine location and spread of tamarisk at Lake Mead.

In 1975 a tamarisk removal project was undertaken in the Newberry Mountains. Five springs were identified for tamarisk removal. Removal procedures included cutting the plants with chainsaws and/or loppers and treating the stumps with Silvex (Kuron) by direct application. The herbicide was applied by using a small oil can to place the liquid directly on the cut end. In 1978 Silvex was removed from the approved pesticide list and no further work was done on the project.

In 1980, mechanical removal of tamarisk was undertaken at Telephone Cove North and South near Katherine Landing. A bull-dozer was used to remove all tamarisk in the north cove and all but a few plants in the south cove. Approximately 40 plants were left interspersed throughout the south cove to see if these plants would develop into larger shade-like trees that could be used by the public. These plants never did provide a good umbrella-like shade structure with the sun directly overhead but have been used for their shade when the sun is at an oblique angle.

Although total removal by bulldozer in the north cove was accomplished, numerous sprouts were found coming up in the first few months from roots that had not been ripped completely out of the ground. However, impact from the public driving over these sprouts, camping on them, etc., eventually killed all but about two dozen of them. In 1987 these 24 plants are back up to about 8-12 feet tall and are used by some campers for shade. They are about 100 feet from water and most campers prefer to be right at the water's edge.

In 1983 an experimental project was undertaken along the river portion of Lake Mohave upstream from Willow Beach. Four test plots were established on a tamarisk-covered beach area adjacent to the river. Four methods of removing tamarisk were used: thinning and pruning, clear cutting, slash and burn, and standing burn. A report by Charles Luttrell (1983) discusses in detail the background procedures and results of this project. A follow-up report gives results of 16 weeks of repeated treatments. The results of this project indicate that no one method would kill the tamarisk in one application, but a campaign of repeated attacks substantially reduced the amount and vigor of sprouting

and with several applications, it may be possible to completely kill the root system. No herbicides were used on this project.

The last attempt at removing tamarisk at Lake Mead was in April of 1986. This project was to remove tamarisk from a beach area near Cottonwood Cove. Approximately 400,000 square feet of tamarisk was removed by chainsaw. Again, no pesticides were used on this project, although follow-up treatment with pesticides may be used. No follow-up information is available at this time.

Proposals for future tamarisk removal projects will be aimed primarily at important springs,especially those that are located more than 1 mile from the shores of Lakes Mead and Mohave. Secondary emphasis will be placed on removal of tamarisk from selected beach sites that have become impenetrable thickets, are health and sanitation problems, and have reduced the public use and enjoyment of preferred beaches.

Initial inventory work will be undertaken as a first step in documenting the tamarisk problem. Springs will again be inventoried for extent of tamarisk present and photo points will be established for monitoring. Beach sites will be selected on a basis of desirability for public camping and day use. These beaches are usually found in coves and are composed mostly of sand. This work will begin in the fall of 1987 and continue through 1988 if funding can be obtained.

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WUPATKI NATIONAL MONUMENT
TAMARISK AND CAMELTHORN
ERADICATION PROGRAM 1983-88

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Wupatki National Monument is located in north-central Arizona. The monument includes a cold desert shrub community of approximately 18,000 acres, which has five different plant associations dominated by four-wing saltbush, Rabbitbrush, Apache plume, and Mormon tea. The desert soils in the monument include Moenkopi sandstone and shales with portions of the Petrified Forest member of the Chinle formation at lower elevations (4300 feet) near the Little Colorado River. Annual precipitation averages 7-9 inches. Elevation ranges from 4300 to 4700 feet. Soil temperatures at the treatment sites ranged from 26-31 degrees during the 1987 field season.

Wupatki National Monument was set aside to protect remains of prehistoric cultures occupational sites, check-dams, and reservoirs from the period ca. A.D. 1100-1250. The Wupatki Basin, outlined by late Quaternary basalts of Woodhouse Mesa, was later occupied by Navajo from ca A.D. 1850-1930.

Tamarisk (*Tamarix ramosissima*) and camelthorn (*Alhagi camelorum*) are codominants at isolated sites in drainages, seeps, and springs, and historic Navajo occupation and corral sites. There are 48 sites with tamarisk, 14 sites with camelthorn, and 17 sites with both species present; 4 prehistoric and 12 historic sites are impacted by the invasion of the plants and 4 seeps (intermittent, low volume springs) and 7 prehistoric reservoirs were impacted by the plants. Three abandoned borrow pits, used for road construction in the 1950s and 60s hold water occasionally and contain both species. Several tamarisk sites are in the bottom of moderate to large size drainages where water collects following high runoff.

Prior to my arrival in 1981, records indicate interest in camelthorn census work beginning as early as 1976; 62 acres of camelthorn and 66 acres of tamarisk were measured from ground plots. A maximum of 8,900 tamarisk plants were estimated per acre in a sump near the Little Colorado River.

Three products were on hand for the treatment of camelthorn: Hyvar-X powder (bromacil), Roundup (glyphosphate), and Weedone 170 (2,4-DP and 2,4-D product). The Hyvar-X and Weedone 170 were disposed of in winter of 1981.

An initial control program began in the spring of 1982 when three large (8" diameter) trees were cut, stacked, and burned. In June, stumps were peeled to expose cambium. Stumps and foliage were sprayed with 2% Roundup solution. Stumps were then covered with Hypalon, an approximately 50 mil thick black fabric used as liner for evaporative sewer lagoons. The regrowth which occurred that summer was treated with 1% foliar spray of Roundup. The site is in the bottom of a large drainage and no regrowth has occurred since initial treatment. Local red-spotted toad (*Bufo woodhousei*) populations flourished initially as they took advantage of cover, in the form of the fabric over the stumps. The site does become inundated with heavy runoff infrequently.

During the summer of 1983, exotic species funding supported two seasonals. Initial work was to conduct a census of the Wupatki Basin (approximately 18,000 acres) cut by drainages of varying depth, concentrating on seeps, springs, large drainages, and then smaller-order tributaries. The Wupatki archeological site survey crew was informed to watch for isolated sites. Sites ranged from single trees to more than 150 clumps.

Two individuals were certified as pesticide applicators through the State of Arizona program (right-of-way test). Tamarisk was treated with cut-stump/frill treatment using Tordon (undiluted) at 30 sites. Camelthorn treatment was 7:1 (water:Garlon) Garlon 3A with surfactant at 17 sites. The initial summer's work (1983) included 94% control of tamarisk and 80% control of camelthorn.

In 1984-86 I returned to plots as time allowed. Camelthorn was also treated with the Garlon mixture. No regrowth of tamarisk was noted. Some areas had an increase of camelthorn density (50-60%). Additional seasonals were used as available and worked under my supervision as a certified pesticide applicator.

The eradication program was funded again in 1987, as one seasonal and I underwent state certification. The 1983 field season application log and base map overlays were used to locate and check previous treatment results and map other areas which had not been treated. During the 1987 season we located six additional sites with camelthorn (up to 3,000 plants in one site). The tamarisk treatment continued to be cut-stump/frill type with an application of Garlon 3A 1:1 mixture to the stump. Often a pulaski was used to grub around the base of plants to expose a central stem which was then cut and treated with Garlon 3A. Most sites had clumps of tamarisk ranging from 1-100 clumps per site.

Camelthorn regrowth occurred sporadically. The number of clumps decreased in 9 sites, increased in 4, and remained the same in 4 sites. During 1987, 15 new camelthorn locations were observed along the road shoulder. Regrowth indicates that local borrow material used for road construction purposes in 1980-84 (46 miles

of road shoulder) may be a continual maintenance problem in the future.

Application methods include 1.5 gallon "Spray Doc" applicators with a hand-pump in the lid. The sprayers are heavy gauge plastic, portable, and easy to clean and maintain as repair kits are available at local hardware stores. The low-volume sprayers are ideal for numerous isolated sites which have few plants and are relatively close to the road. In 1988, a 4-gallon SOLO backpack pump was used. It too is an excellent tool and is more efficient in terms of mixing large quantities for large plots of exotics. Personal safety equipment includes plastic goggles, cartridge-type respirators, rubber gloves, and long-sleeve NOMEX fire shirts for camelthorn and tamarisk treatment.

A combination mechanical/chemical method was tried for both species. An Echo weed-eater with an 8" steel brush blade was used to sever small stems and followed quickly by an application of herbicide. Test plots were tried for undiluted Garlon, 1:1 Garlon, and no treatment. No regrowth had been noted in any plot by the beginning of the 1988 field season. We have submitted root cross sections to the State of Arizona Horticulture Department to determine extent of tissue death of roots at 30-40 cm below ground level.

Problems foreseen in the control program are desirable fall application periods with summer funding programs. In 1987, we also tried pulling plants out as much as possible before stripping the cambium and applying herbicide. A 1-ton vehicle with winch was also used to pull large plants from drainage bottoms followed by treatment of the roots. The vehicle method does not work well with clumps composed of small, whip-like branches as the cable and chain cannot bind on the stems.

A disadvantage with the weed-eater is that although it runs at a fast speed (2000 RPM) the motor cannot maintain torque and gets bogged down with small branches. Another disadvantage is that the person following with herbicide cannot follow closely enough, for safety reasons, and does not see all clumps that have been severed. The stems must be trimmed to within 1" of the ground surface to be effective.

Logistic problems include the numerous sites scattered across the desert drainages. Heat exhaustion symptoms were evident on more than one occasion. A minimum crew of two people is essential for several safety reasons. A minimum of 2 quarts of water per person is essential as was additional freshwater for rinsing in case herbicides were spilled during mixing operations. For sites which were distant from the road, a 5-gallon bladder bag without a hand pump was used to carry water for mixing and safety purposes.

We have a good handle on location and control of tamarisk at Wupatki. The isolated nature of the plant in drainages will be a constant surveillance problem to insure plants do not become established and act as seed sources for other plants. There is a problem in that several large trees are located outside the monument on private land in drainages which do act as seed sources. Several of these trees provide shade for livestock and their loss would be looked upon unfavorably. It is not feasible to remove all trees on the boundary along the Little Colorado River due to the massive acreages of seed sources above and below our location. We consider the removal of plants from isolated locations as a goal and to keep plants "in check" at the river or sump location.

Camelthorn will be a constant maintenance problem along road shoulders as will mullein, sweet clover, and cheat grass. It is extremely important to check road shoulders before plants become well established with long tap roots and substantial reserves. Camelthorn plots have been treated repeatedly since 1983. The density is decreasing. Applications have varied between early spring to late fall, with multiple applications in a season to treat regrowth.

In 1988, Arsenal was approved for use at Wupatki. In addition to a seasonal, a student conservation aide was funded. This two-person crew was trained in a similar manner to monitor previous treatments and apply herbicides. In addition to the surfactant used, a dye Blazon was mixed with the herbicide. The color helped to verify that plants had been sprayed when working in large plots.

HERBICIDE EFFECTIVENESS

The large trees (stump diameter 8-10") treated in 1982 by covering stumps with heavy, black Hypalon liner material have not shown any regrowth. The trees were cut during the dormant season and brushed with Roundup. The actual herbicide itself may have been ineffective as it was several years old. The initial regrowth which occurred in the spring or summer was without chlorophyll and probably susceptible to foliar spray of Roundup. No cut stump temperatures were recorded beneath the black liner. If air temperatures were at 100 degrees F, the surface temperature beneath the black liner was undoubtedly much higher. Plots which were treated in 1983 with Tordon RTU as a cut-stump/frill treatment show no signs of regrowth. Plots of up to 100 clumps which were cut and treated by the same individual have not had any regrowth. The use of sandviks or pulaskis is essential to expose below ground cambium prior to the herbicide application.

Plots of tamarisk which were cut with the Echo weed-eater prior to treatment showed resprouting. This may be the result of excess stem height or from the applicator not seeing all the clumps which had been cut. For example, at one location of 87 plants, 20 showed signs of regrowth. In areas where individual trees were cut with the weed-eater prior to application, regrowth was also spotty.

The Arsenal applications during 1988 were foliar sprays of a 2-3% solution with Blazon dye. Yellowing occurred within 3 weeks after application and dried scale leaves persisted on the plants until late summer. No regrowth was evident at basal stems the same season as the application. Most applications were made during mid-day time periods with air temperatures seldom below 90 degrees F. Arsenal applications on camelthorn were made side-by-side with Garlon 3A treatments. The Arsenal cut-stump treatments were less effective (78-82%) whereas Garlon 3A cut-stump was effective (85-92%). The foliar spray with both herbicides was 80-90% effective but final decision on effectiveness will not be determined until the 1989 growing season.

In summary, the effective herbicide to date has been Tordon with a cut-stump/frill treatment. This two-step process is slow but individual clumps do not show regrowth. The cost of Tordon was less than Arsenal, which was tested in 1988. For large trees with massive trunks, a cut-stump treatment should be the preferred course of action. For large areas, foliar spray would be easier, but economical considerations for cost of herbicide must be considered. In a large stand, it would soon become impassable as trees are fallen and stumps treated. Time-delayed applications three to four weeks apart would allow time for the herbicide to show effects to avoid spraying single trees more than once. A disadvantage of spraying large stands is that overspray would affect other groundcover in the immediate vicinity. From our standpoint, the management objective for tamarisk is to keep it in check along the river, and remove it from isolated pockets or locations within Wupatki Basin. Camelthorn is to be removed from archeological sites, road shoulders, and isolated locations within Wupatki Basin, and kept in check in the area immediately adjacent to the Little Colorado River.

ACKNOWLEDGEMENTS

I would like to acknowledge the personnel who have helped with this project in the past: Bruce Palmer, Demica Vigil, John Mulder, Margaret Rasmussen, Dianne Yaucoub, and Kara Paintner. Their unsung efforts have helped improve the natural landscape at Wupatki National Monument. I am indebted to them for long, hot hours of eradication efforts and good record keeping.

SUMMARY REPORT ON TAMARISK CONTROL: JOSHUA TREE NATIONAL MONUMENT

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ABSTRACT

In 1984, a systematic monitoring and control program for *Tamarix ramosissima* was initiated at Joshua Tree National Monument. Monitoring of known locations for tamarisk occurrence is undertaken on a routine basis. The control program utilizes mechanical methods, accompanied at some locations by the piling and burning of cut debris. Plants are cut using chainsaws, axes, and pulaskis. The resulting vegetative debris is removed from areas which still contain a water source when possible in order to prevent seed dispersal or sprouting. In very arid areas where the water source no longer exists, the cut debris is piled on the stumps from which it was cut and the pile is burned.

Joshua Tree National Monument lies along the transition zone between the Mojave and Colorado deserts in southern California. The unique interface between the Colorado and Mojave deserts has created a spectacular diversity of plant life. Native vegetation representative of both deserts is present in the monument. The principle resources which the monument was established to protect are these native desert vegetation systems.

Precipitation in the monument ranges from 1 to 5 inches annually, but has been decreasing in recent years. Natural water sources are extremely rare. Perennially flowing streams are nonexistent. Although there are 5 native fan palm oases and approximately 200 springs, most seeps and springs are intermittent and unpredictable. Water loss from exotic vegetation encroaching upon springs has the potential to seriously impact the monument's wildlife.

The monument's Resource Management Plan identifies exotic plant control as a major resource problem under project statement RM-7. The exotic of greatest concern to the monument, because of its occurrence at desert water sources, is tamarisk. Two species of tamarisk are present in Joshua Tree National Monument. *Tamarix aphylla* and *Tamarix ramosissima* have been documented to occur at 14 different locations. These locations are widely spread throughout the 500,000 acres of the monument and include springs,

oases, several small lakes, old home sites,and remote wilderness areas. *Tamarix ramosissima* is the far more common of the two species, occurring at 12 of the 14 areas.

A search of the park files reveals that tamarisk first became an important concern at Joshua Tree in the early 1970s. In 1976, tamarisk plants were cut and their stumps treated with Silvex at Keys Ranch, Cow Camp, and other remote locations. No documentation on the success rates of this chemical treatment, however, is available. This lack of an information resource base leaves little indication of the extent of past control programs or the success of those programs. No useful historical photographs have been found. However, some comparison can be made from written descriptions. For example, a memorandum dated June 1975, reports that Cow Camp was at that time heavily infested with tamarisk, the northeast end of the pond area being densely covered with both large and small trees. In 1984, three clumps of tamarisk were removed at Cow Camp, mostly saplings of 1/4 to 1/2 inch diameter. Thirty-five plants have been removed this year, again mostly very small saplings. Whether this apparent reduction in the amount of tamarisk at Cow Camp is attributable to the past application of Silvex is difficult to say. Between 1976 and 1984, tamarisk control was undocumented, but probably consisted of sporadic mechanical removal.

In 1984, a systematic monitoring and control program was initiated. Reliable records are, therefore, available from that year forward. Tamarisk was removed from 5 sites in the monument in 1984, with 4 additional operations during 1985 and 1986. The receipt of $2,400 from Cyclic Maintenance funds for exotic plant control for FY87 boosted the number of sites where tamarisk could be removed this year. Thus far in 1987, control efforts have been undertaken at 10 of the 14 areas and removal from the other locations is scheduled to be carried out. The current control program utilizes a combination of mechanical methods and fire, relying most heavily on mechanical removal. Plants are cut using chainsaws, axes, and pulaskis. The resulting vegetative debris is removed from areas which still contain a water source in order to prevent seed dispersal or sprouting. In very arid areas where the water source no longer exists, the cut debris is piled on the stumps from which it was cut and the pile is burned.

Two such burns have been undertaken to date. One involved *Tamarix aphylla*, while the other was *Tamarix ramosissima*. These burns appear to have resulted in a 100% success rate in killing both species. It should be noted, however, that these burns took place in very arid areas, i.e., areas usually considered too arid for tamarisk. Several more burns have been scheduled for this winter. Success rates will be monitored and documented.

Although the current tamarisk control program provides excellent documentation of control sites, including the method and number of plants removed, more comprehensive documentation is needed. Individual plants need to be tagged so that follow-up visits can record the percentage of sprouting. This increased monitoring of individual plants pre- and post-control will allow for a better assessment of actual success rates for the various sites.

Because the monument is not currently using herbicides, mechanical removal should be carried out in winter during the plants dormant period in order to reduce seed dispersal. Due to the time of year funding has been obtained, this has not always been possible in the past. In addition, over 80% of the monument is designated wilderness. Travel to remote areas where tamarisk occurs is time-consuming and difficult. The removal of tamarisk debris from such sites is impractical and many of these areas are unsuitable for burning. Conducting control work in winter should lessen concerns regarding the spread of *Tamarix ramosissima* subsequent to cutting in these remote areas.

Currently, only those areas known to contain tamarisk are monitored on a cyclic basis. Some of the more remote springs have not been visited in recent times. It is possible that tamarisk is more widespread than is currently thought. A survey of all known water sources in the monument is planned when future funding can be obtained. Ideally, this would be possible on an ongoing basis in order to check any future spread of tamarisk in the monument.

TAMARISK ERADICATION EFFORTS AT GUADALUPE MOUNTAINS NATIONAL PARK, TEXAS

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ABSTRACT

Guadalupe Mountains National Park has undertaken a program to locate and eradicate *Tamarix ramosissima* which occurs within the boundary of the park. This program is necessary in order to eliminate this nonnative plant that has invaded the park. Large specimens at water sources can have a detrimental impact on wildlife by causing severe water loss through transpiration. In order to prevent such degradation, a program to eradicate the plants from the park is outlined below.

INTRODUCTION

Tamarisk, also known by its common name of saltcedar was first introduced into the United States in the early 1800s from Asia as an ornamental tree, as a windbreak, and for streambank erosion control. A deciduous shrub or tree, it is known to grow up to 30 feet and is a rapid colonizer and vigorous invader of disturbed Southwestern habitats. Seeds are numerous, mobile, rapidly germinating, and requiring water. They prefer streams, salt flats, sandy lands, and marshes. Once established at a water source, tamarisk dry up water sources critical for wildlife use, providing poor food and shelter for the same. During the summer of 1987, the Southwest Regional Office provided funding to the park for tamarisk eradication. The funds are presently being used for buying the approved herbicide and supplies, and for additional reconnaissance for other tamarisk in more remote areas of the park.

STUDY AREA

Guadalupe Mountains National Park is located in southwestern Texas (see Figure 1). The park was set aside in 1972 to protect and preserve 76,293 acres (119 square miles) of land possessing outstanding geologic values, and other natural features of great significance. Guadalupe Peak, the highest peak in Texas, is located within the boundary of the park. Elevation ranges from 3,650 feet at the base of the western escarpment to 8,749 feet at Guadalupe Peak. Plants of the Chihuahuan Desert such as creosote, ocotillo, and yuccas are found in the lower elevations

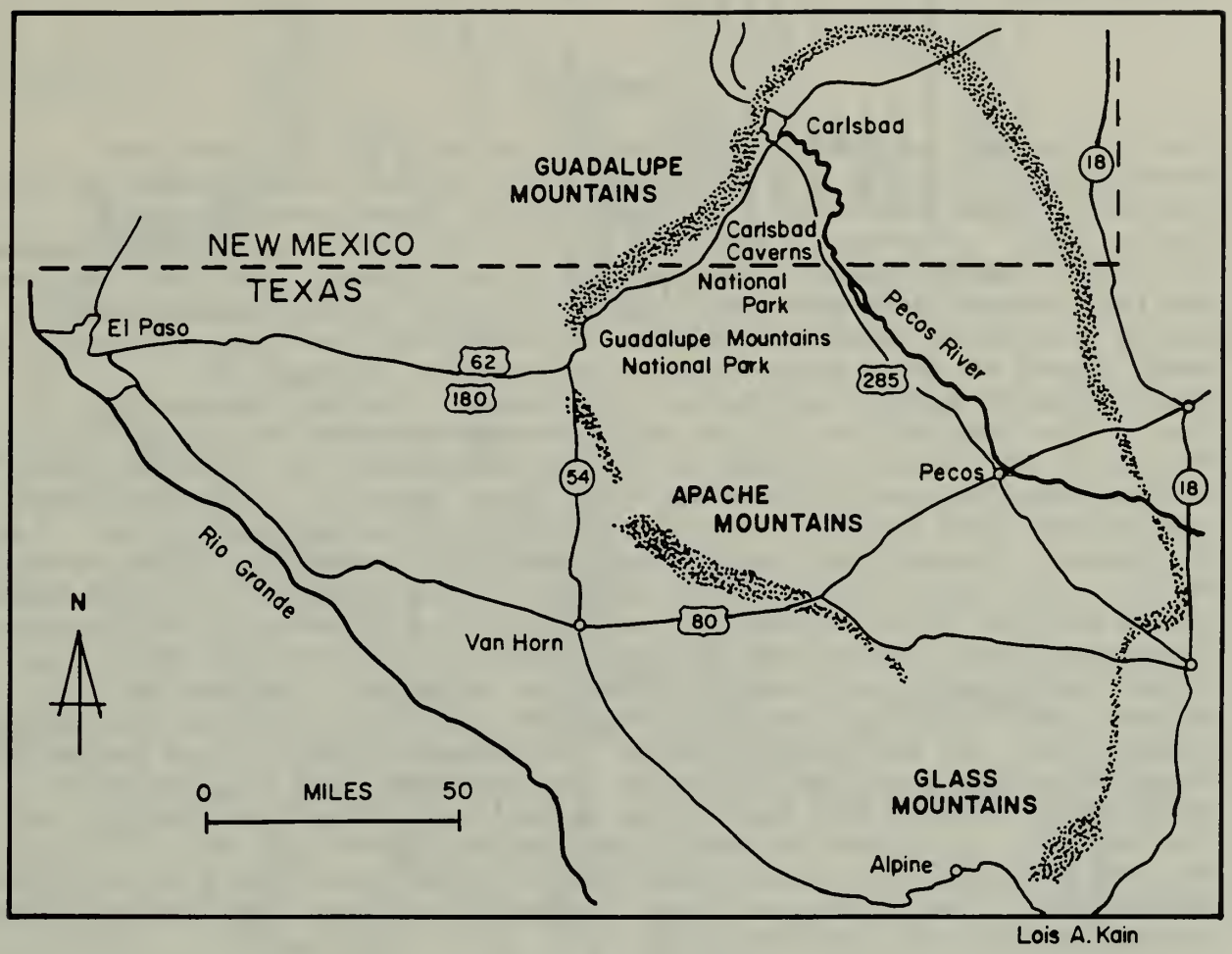

Figure I. Regional Map of the Study Area.

Most of the 400-mile-long Capitan Reef lies buried but in three mountain ranges- The Guadalupe, Apache and Glass Mountains- it stands above the surrounding plains as high as 4000 feet.

with remnants of a relict forest that include ponderosa pine, southern white pine, douglas fir, and a few aspens at the higher elevations.

METHODS

In the summer of 1985, an extensive survey of the park was conducted to locate and document the location of tamarisk within the park (see Figure 2). A total of 27 trees were located. Since then, however, a few new trees have been found which brings the total to 33 trees. During the 1985 survey, specimens at two springs--Choza and Bone springs--were also photographed using a photo reference system. Before any eradication work is done, each plant at each site will be documented as well as photographed before and after treatment. During the summer of 1987, the Washington Office approved the herbicide Garlon 3A as the only herbicide available for the treatment of tamarisk on lands administered by the National Park Service. Trees will be cut flush with the soil using chainsaws, brushcutters, and handsaws. Immediately after cutting, the stumps will be treated with a wick applicator using Garlon. This application will take place within five minutes of cutting. The trees will be removed completely and taken out of the area. If not removed from the area, new growth can result from the cuttings. At one of our sites, just off State Highway 62/180, due to the large number of trees (21), we are proposing to burn the stumps without removing them from the area and to study the effects fire will have at this site. There are two sites where the trees are growing in the water. In order to avoid contamination of the water source, we are proposing to remove the plants physically with no chemical treatment. The plants will be removed from the area and the root system pulled out as possible.

After the fall 1987 treatment of plants is completed, an extensive monitoring program will take place using visual visits and documenting the sites using the photo witness reference system to measure treatment methods effectiveness. Once a month visits to the treated sites will take place as well. Retreatment, if necessary, will take place during the fall of 1987. Results will be summarized in the annual tamarisk project summary report.

SUMMARY

To date, Guadalupe Mountains National Park has a limited number of tamarisk trees growing within the boundary of the park (33). Careful analysis and use of a herbicide (Garlon 3A) as well as treatment of stumps by the park staff could completely eradicate tamarisk from the park. During the fall of 1987, the greatest

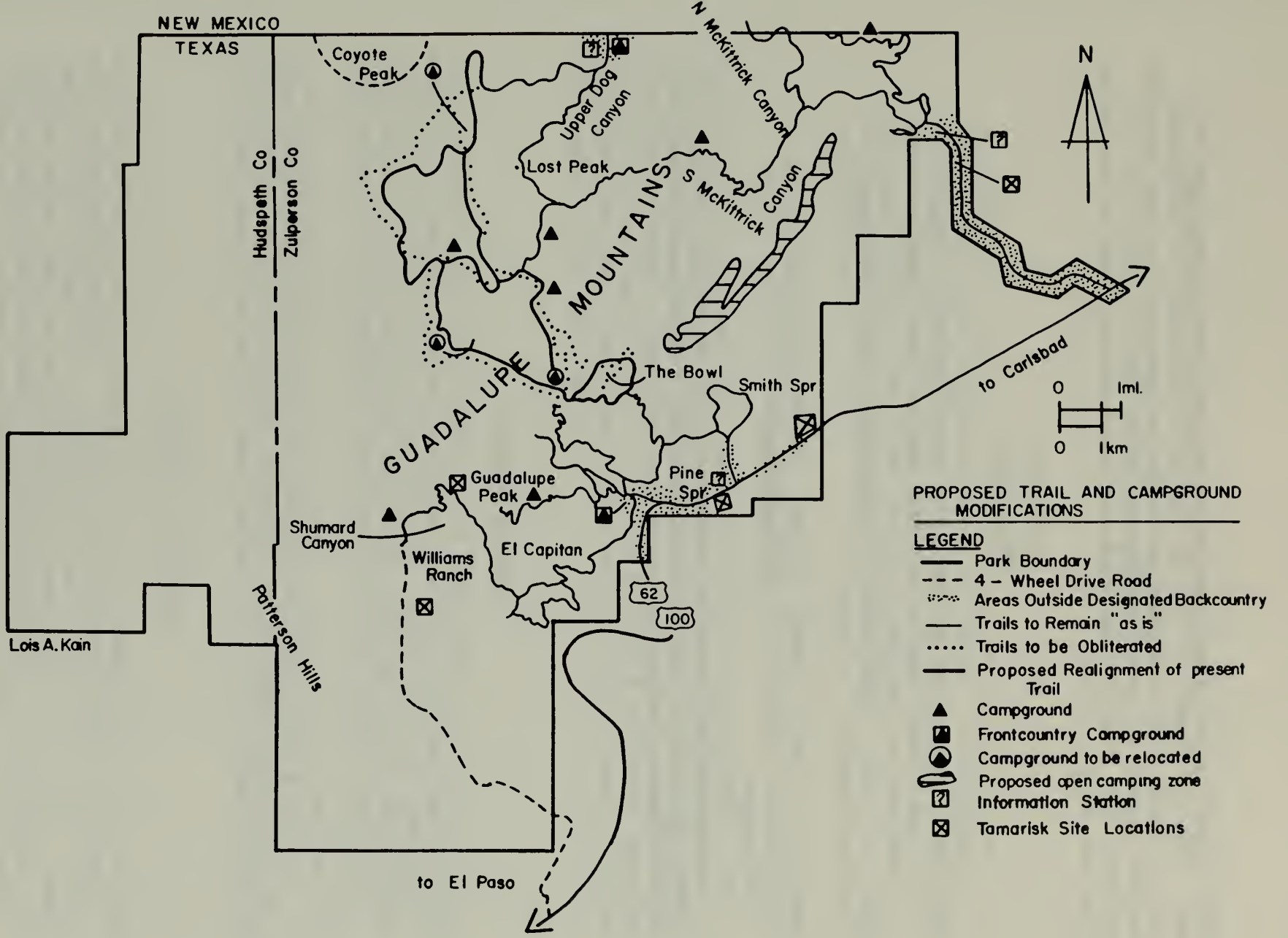

Figure 2. GUADALUPE MOUNTAINS NATIONAL PARK / TEXAS

effort will be put forth by the park staff to accomplish this goal. The greatest threat to the park, however, is untreated areas outside the park that provide the seed source for tamarisk. The park hopes to provide assistance to area ranchers in the treatment and eradication of tamarisk once the results are known after the fall of 1987.

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STATUS REPORT ON TAMARIX IN BIG BEND NATIONAL PARK

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ABSTRACT

At least two species of *Tamarix* are currently found at water sources in Big Bend National Park. A deciduous species has invaded 66% of the park's backcountry water sources away from the Rio Grande floodplain. Past control efforts have been largely ineffective because of suspected poor timing and poor treatment application.

INTRODUCTION

Big Bend National Park is a land of dramatic contrasts. It contains a nationally significant example of the Chihuahuan Desert, the spectacular Chisos Mountains, and a 118-mile segment of the Rio Grande, which defines the park's southern boundary. The Chihuahuan desertscape is 87% of Big Bend National Park and contains more than 200 backcountry water sources, many of which have been invaded by *Tamarix*.

TAMARIX HISTORY

Big Bend National Park has at least two species of *Tamarix*: an evergreen species, one of which is currently listed as a national champion "Big Tree" with the National Association of American Foresters; and at least one deciduous species which has invaded backcountry water sources away from the Rio Grande floodplain.

A water source survey in 1976 found 74 of 181 water sources with some degree of infestation of deciduous *Tamarix* for a 41% infestation rate. A recent resurvey, 1985-1986, found 150 of 227 water sources infested to some degree for a 66% infestation rate.

CONTROL ACTIVITIES

Control efforts were initiated in 1976, when Silvex was utilized as a stump application. In 1977, $4,500 was spent on *Tamarix* control and a crew was scheduled to work *Tamarix* in 1979. Water sources were checked and treated sporadically until 1983, when $10,000 was made available and approximately 29,000 plants were treated with a stump application of Tordon RTU. Unfortunately,

little follow-up work has been completed, and a good basic review of past control efforts has yet to be accomplished.

Three herbicides have been utilized in the past as stump applications: Silvex, Hyvar, and Tordon RTU. A fourth herbicide, Garlon 3A, is currently approved for *Tamarix* control in the Southwest Region. At best, I would speculate that 60-75% of the park's control efforts have been ineffective because of poor timing.

Timing of application, with respect to both time of year and time after cutting, has, I suspect, been inappropriate in most control efforts. Many treatment applications have been in late spring and summer. During periods of hot weather, unless the herbicide is applied immediately after cutting, herbicide application is probably having little effect.

Several basic concerns must be addressed before effective, short-duration control efforts should be initiated:

1. The timing of greatest susceptibility to treatment should be determined.

2. A relatively high mortality rate/treatment effort is needed.

3. Timing of funding to field manpower must occur to maximize treatment success.

FUTURE ACTIVITIES

The park's current priorities for monitoring and treatment of water sources are as follows:

1. Water sources in the high Chisos Mountains. These sources have yet to be invaded and will be checked at least annually for the presence of *Tamarix* (10 water sources).

2. Springs and drainages that receive heavy visitor use, particularly those near established trails and roadside campsites (36 water sources).

Degree of infestation

None	-	10
Light	-	14
Moderate	-	6
Heavy	-	6

3. Water sources with cottonwoods present, other than #2 (121 water sources).

Degree of infestation		
None	-	57
Light	-	34
Moderate	-	12
Heavy	-	18

4. Other water sources with varying degrees of infestation (60 water sources).

5. Rio Grande floodplain.

Current proposed treatment for the remainder of FY87 and into FY88 is the use of Garlon 3A as a stump application, and when and where feasible, the use of black plastic to cover the stumps. Project Statement #BIBE-N-007 in the park's Resource Management Plan calls for the development of an IPM plan for *Tamarix* and a control and monitoring effort for at least the next five years at approximately $32,000/year for control and monitoring and $30,000 to develop a comprehensive IPM plan for *Tamarix*.

TAMARISK ERADICATION IN ZION NATIONAL PARK

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ABSTRACT

An objectives-oriented program of saltcedar (*Tamarix ramosissima*) eradication was begun in Zion National Park in 1987. Control is through stump cutting and treatment with Garlon 3A (Dow Corp.). Monitoring plots were established to determine success rates of the treatment and treatment periods; representative June treatments were 88% successful, while similar treatment in February was 62% successful.

Zion National Park is located in southwestern Utah and is managed as a natural area to preserve "an extraordinary example of canyon erosion." The park, located on the Colorado Plateau, is 147,000 acres in size and includes areas of Lower and Upper Sonoran Desert, Transition, and Canadian life zones. The park is located in the upper third of the Virgin River watershed, a major tributary system of the Colorado River.

Tamarisk is found along most of Zion National Park's water-courses. The greatest density of tamarisk is found along the North Fork of the Virgin River between the Temple of Sinawava and Canyon Junction--approximately 7 miles in length. Moderate stands of tamarisk are found along the upper North Fork of the Virgin (commonly known as the Zion Narrows), La Verkin Creek, and the East Fork of the Virgin River. Isolated stands of tamarisk are found along the left and right forks of North Creek, the Taylor Creek drainages, tributaries to the North Fork, and along most other drainages in the park. Isolated tamarisk are found near springs and other wet areas throughout the lower elevations of the park.

Flood regimes (of frequent, high-volume flood events) are such that tamarisk is kept at low to moderate densities in most drainages; however, in areas of lesser flooding frequency, such as oxbows, the plant has begun to form dense, impenetrable thickets.

A tamarisk eradication program was begun in 1987. Objectives of the program are: to prevent saltcedar invasion from altering succession in riparian ecosystems; to prevent the development of dense thickets that potentially stabilize riverbanks and oxbows; and to eliminate potential influences to other community components and processes.

Tamarisk eradication efforts started in February, but the majority of the work was not begun until June. The Zion Narrows section of the North Fork of the Virgin River was the target area for eradication this first year. The upper North Fork is a 12-mile stretch of narrow canyon and isolated sandbars and benches. The higher benches support the largest, densest stands of tamarisk. Flash floods help reduce the stands in the other areas. Heavy stands of tamarisk are found along 1 mile of the upper Virgin. Moderate stands are found along 3 miles of the river, with no tamarisk being found along approximately 4 miles.

The control method was to cut each tamarisk down and treat the stump or stem with the herbicide Garlon 3A. Garlon was applied to the stem with a brush (concentrating on the phloem and cambium layers).

No success rates have been determined for the treatment in the Zion Narrows, but several test plots (Table 1) were set up in the Big Bend area of the Virgin River (in upper Zion Canyon), south of the Temple of Sinawava. (The Big Bend area has the largest stand of tamarisk in Zion National Park.)

Plots 1-4 were treated in June 1987; the tamarisk were cut and treated with herbicide on the same day. The tamarisk in plots 5 through 10 were treated in February; plots 5-7 were treated two to five days following being cut, while those in plots 8-10 were cut and treated on the same day.

The plots were 100 square feet in size. The tamarisk were placed in one of three categories: 1) dead, 2) sprouted but dying, and 3) living. Dead tamarisk were those showing no signs of sprouting. The "sprouted but dying" tamarisk sent up small shoots which died or appeared to be dying. Living tamarisk had sprouts which showed little or no signs of browning or wilting.

The test plots which were treated in June showed an 88% kill rate. The plots treated in February showed less successful results: 62% kill rate for those treated immediately after cutting, and 10% kill for those treated two to five days following. Few treatment-related impacts on nontarget species have been noted. Two dead willows were found in one of the test plots; however, it is not known if their deaths were related to the treatments.

A plan for a five-year program of tamarisk eradication in Zion National Park is being prepared. The plan will contain a timetable for treatment of existing tamarisk stands, as well as the framework for a permanent monitoring/maintenance program for future management of the species. It is hoped that the major eradication efforts can be undertaken by contract labor, using the now available fees money, while the monitoring/maintenance work that follows can be integrated into NPS operations as a part of resource management or backcountry patrol functions.

Table 1. Results from Tamarisk monitoring plots in the Big Bend area of Zion Canyon (August 24, 1987).

Plot	#Treatment Date	#Treated	#Dead	#Sprouted but dying	#Sprouted	% Dead
Plots 1-4; cut and treated the same day.						
1.	6/87	53	31	10	12	77%
2.	6/87	35	25	9	1	97%
3.	6/87	33	21	8	4	88%
4.	6/87	45	40	3	2	96%
		166	117	30	19	88%
Total sample size = 400 sq. ft. Total treated area = 4250 sq. ft. 9% of total area was sampled.						
Plots 5-7; cut, and then treated 2 to 5 days afterward.						
5.	2/87	36	4	0	32	11%
6.	2/87	25	0	0	25	0%
7.	2/87	43	6	0	37	14%
		104	10	0	94	10%
Total sample size = 300 sq. ft. Total treated area = 1500 sq. ft. 20% of total area was sampled.						
Plots 8-10; cut and treated the same day.						
8.	2/87	35	25	0	10	71%
9.	2/87	38	32	0	6	84%
10.	2/87	48	17	0	31	35%
		121	74	0	47	62%
Total sample size = 300 sq. ft. Approximate total treated are = 900 sq. ft. Approx. 30% of total area was sampled.						

STATUS OF SALTCEDAR (TAMARIX RAMOSISSIMA) WITHIN GLEN CANYON NATIONAL RECREATION AREA

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ABSTRACT

Glen Canyon National Recreation Area was established in 1972 to provide for public outdoor recreation... and to preserve the scenic, scientific, and historic features of the area. An important component of the environmental setting, the shoreline vegetation communities, are in juvenile stages of development, the composition of which is a monoculture of saltcedar. The National Park Service is monitoring the establishment and growth at selected saltcedar stands and developing strategies for the long-term management of Lake Powell's shoreline communities.

Glen Canyon National Recreation Area comprises 1.25 million acres located along the Colorado River channel in northern Arizona and southern Utah. The Glen Canyon Dam closed its flood gates in 1963 and began filling what would become the 163,000-acre Lake Powell. The lake attained full pool in 1980 (3,700 feet) and flood level (3,707 feet) in 1983. Saltcedar has only recently become established in sites where it will no longer be inundated by seasonal Colorado River flows and fluctuating lake levels. Lake Powell thus provides a unique opportunity to investigate the developing shoreline riparian community.

Potter and Pattison (1976) assessed the shoreline ecology of Lake Powell at various lake levels. At full pool, the shoreline of Lake Powell was estimated at 1,822 miles. Of this, 1,033 miles are sandstone cliff or shelf terrace with an additional 372 miles of sandstone with a thin sand or gravel mantle. These areas totaling approximately 1,405 miles lack suitable habitat for saltcedar invasion and establishment. The remaining 475 miles can be characterized as alluvial or sandy beaches where saltcedar is becoming established.

In the habitat where the establishment of saltcedar is occurring, limited sampling has been initiated by the park. The primary habitat appears to be gentle sloping beaches of 1 to 5% with a gravel or sand base. The developing stand can be subdivided into two zones: a seedling zone which is inundated each year, and a perennial saltcedar zone. The majority of plants in the mature saltcedar stands measured less than 2 meters in height in 1985.

Recreational visitors on Lake Powell prefer the sandy beaches over other shoreline types. This preference tends to concentrate visitors into less than one-fourth of the lake's shoreline. An analysis of the recreational carrying capacity of Lake Powell was completed in 1987, which indicates the area is approaching its physical capacity as determined by the available campsites. Saltcedar thickets will reduce the number of available sites, limiting the area's capacity for recreational use. If management techniques (thinning to select for larger individual trees with an open understory) can be developed, saltcedar could become tolerable by providing cover as well as enhancing shoreline stability.

The developing shoreline community dominated by saltcedar is in its early stage of development, yet an increase in riparian habitat could be an important factor in the continued utilization of the recreation area by the endangered peregrine falcon. In fact, as this riparian community develops it is anticipated that there will be a corresponding increase in the prey base for the peregrine falcon. Szaro and Belfit (1986) reported species diversity is more important than the structure of the developing shoreline community for wildlife habitat in a similar situation is southern Arizona. To experiment with this concept, the park is proposing to introduce cottonwood and willow seedlings into selected sites to compare and contrast their habitat value.

An inventory of the backcountry free-flowing springs and seeps was initiated in 1985 and a program to expand this effort is included as an issue in the draft Water Resources Management Plan available for public review in 1987. Elements of this program are the analysis of spring water chemistry, inventory of spring flow rates, and a description of the perennial vegetation including a discussion of saltcedar. This program will provide priority sites for eradication and control.

In contrast to the relatively barren shoreline of Lake Powell, the 13 mile stretch of the Colorado River between the Glen Canyon Dam and Lees Ferry supports localized but dense stands of saltcedar dating 30 to 40 years in age. A small stand burned in 1985 and two additional stands burned in the spring of 1987. The fires are believed in all cases to have originated as escaped visitor campfires but illustrated the potential for intense wildfires. Due to this potential for wildfire, the park is collecting data for the development of a Fire Management Plan. The plan, as envisioned at this time, will address only the river riparian habitat.

To investigate the effects of wildfire in saltcedar stand, the park is working with Larry Stevens, a graduate student at Northern Arizona University. The purpose of the study is to: 1) describe the substrate at the burn site, 2) determine the depth to which the fire affected the soil, 3) collect samples that may

be used in future soil analyses, and 4) determine the present soil pH and available nitrogen status in burned and nearby unburned sites. Additional work is proposed which will monitor the recovery of these burn sites and provide fuel analyses for fire planning purposes.

Glen Canyon National Recreation Area offers a variety of habitat and community conditions. The shoreline of Lake Powell offers an excellent experimental setting to investigate developing riparian communities because the Colorado River stands are mature and provide valuable contrast. Additional data are needed to direct park administrators in the management of these diverse and developing resources.

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SUMMARY REPORT ON TAMARIX CHINENSIS LOUR. AT ORGAN PIPE CACTUS NATIONAL MONUMENT

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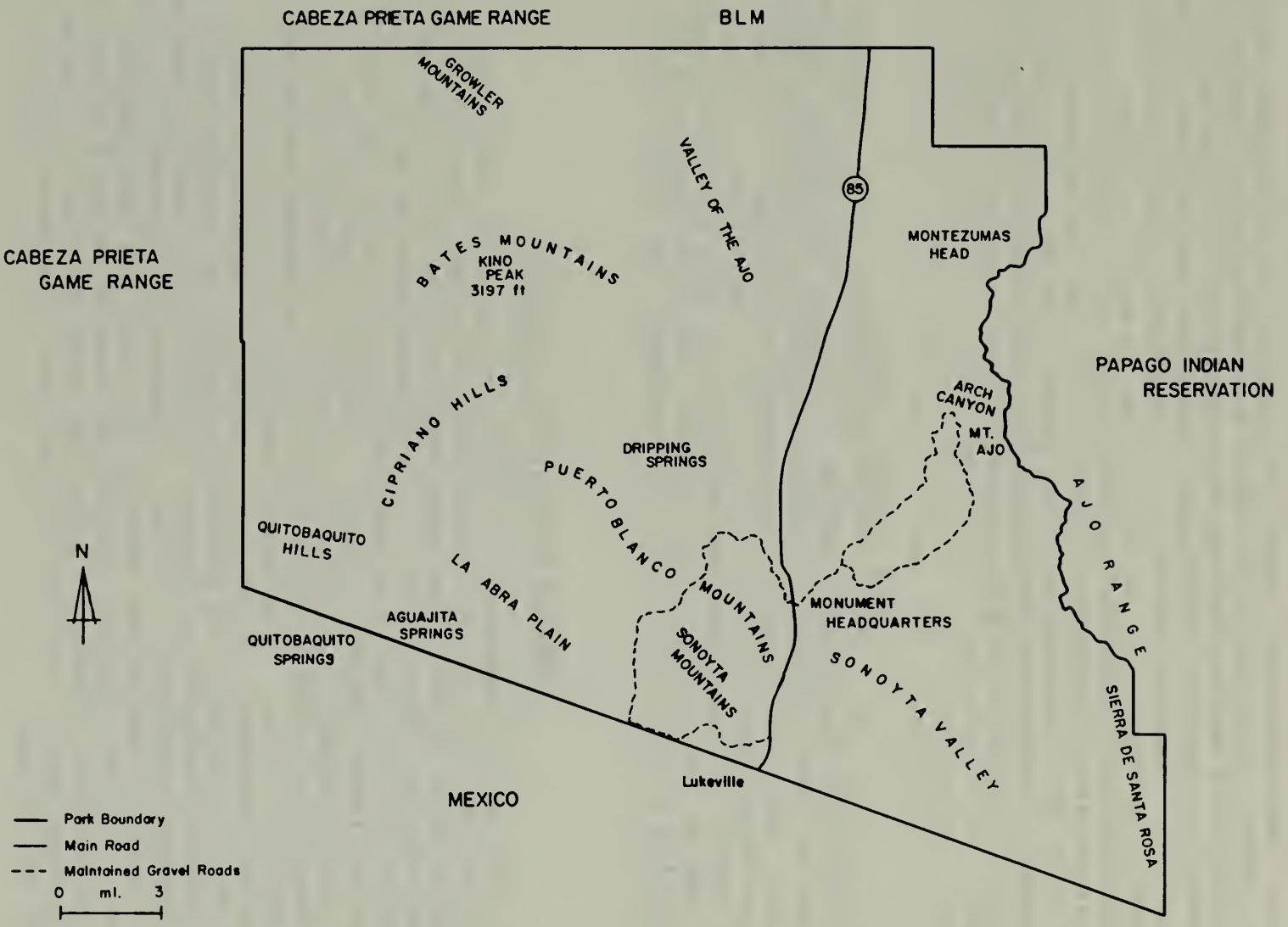
INTRODUCTION

Organ Pipe National Monument is comprised of 330,000 acres of arid land environment which includes two major subdivisions of the Sonoran Desert (Arizona Upland and California Microphyll) and remnants of the Central Gulf Coast subdivision widely scattered throughout the southern one-third of the monument. The climate of the region is typified by mild winters (rarely freezing) and hot summer months with high temperatures reaching well over 100 degrees F. for most days. Rainfall is bimodal which facilitates a spring and late summer growing season.

HABITAT AVAILABILITY

Very little of the total park acreage provides suitable habitat for the growth of the tamarisk or salt-cedar (*Tamarix chinensis*). The monument does contain many miles of dry riparian wash systems that are fed only periodically by violent torrential rains which come during the summer season. Water tables along these stream courses vary in depth but only at one location on the Aguajita Wash (at the International Boundary) can water be found at or within a couple of feet of the surface on a perennial basis. At the Quitobaquito pond/spring complex and further west at Burro and Williams springs, water also reaches the surface at perennial or intermittent times throughout the year. Tamarisk has been located at Aguajita Wash and Quitobaquito Springs and has the highest probability of being located at other sites in this U.S./Mexico border vicinity (Figure 1). Other sources of perennial water within the monument include Dripping Springs, Bull Pasture Springs, and Cement Tank. Tamarisk has not been found at any of these locations.

Despite the general lack of habitat within the monument, the Rio Sonoyta which lies immediately south of the International Boundary provides substrate for thick stands of this tree species. This river comes within 1.5 miles of Quitobaquito, thus providing an excellent source of seed nearest the most susceptible habitat within the monument.



ORGAN PIPE CACTUS NATIONAL MONUMENT

Lois A. Kam

HISTORY OF TAMARISK AT ORGAN PIPE CACTUS NATIONAL MONUMENT

T. chinensis has undoubtedly been established in the Sonoyta Valley along the Rio Sonoyta for at least several decades, providing a plentiful seed source for the few hospitable habitats within the monument. At several locations around the park connected with the earlier livestock operation, tamarisk (*T. chinensis*) was also planted as a shade tree at certain wells and line camps. It is interesting and fortunate that with the long history of human occupation at Quitobaquito Springs, tamarisk was apparently never used there as a shade tree. The present scattered occupation of *T. chinensis* in the Quitobaquito/Aguajita Wash area would appear to be through random seed propagation likely from the nearby Sonoyta River.

PAST CONTROL EFFORTS

Since 1976 and very likely before this time, control of this species has been through mechanical removal by hand with shovel and axe. The environmental assessment for the park's first Resource Management Plan written in 1976 identifies the need for hand removal of this tree and application of a federally approved herbicide to the stump. If chemicals have ever been used for elimination of tamarisk within the monument, no record exists to so indicate.

CURRENT EFFORTS FOR CONTROL

Since 1981 yearly searches for this species have continued, usually during the winter season when volunteer help is more available or at other times when the plant has been reported by another source. Particularly in the later case an effort is made to search for the plants as soon as possible after the report. Despite diligent search efforts, at certain times of year (especially winter), this plant is easily overlooked through the high density of other species within the Quitobaquito Springs and Aguajita Wash areas. Both areas contain very rare (and one endangered) species. Because of the highly aggressive nature of tamarisk, it has been the monument's policy to conduct yearly or more frequent searches if needed. Searches are usually made with 3 to 10 persons spaced to visually observe the greatest diameter, with transect lines walked through the wash and Quitobaquito habitat. Plants found are tagged and removed using a shovel and axe. An attempt is made to sever the root at least 12 inches below ground level. To date no chemicals have been applied to foliage or stumps.

FUTURE CONTROL EFFORTS

Searches will continue for the plant on a regular basis particularly at Quitobaquito and Aguajita Wash. For larger, better established trees the use of an appropriate herbicide may be sought, although to date, no resprouting of previously cut individuals has been observed.

Beginning this year, a more intensive search for the existence of *T. chinensis* in other major wash systems and further west of Quitobaquito will be made as part of a research effort to document the presence of exotics on a parkwide basis. Individual tamarisk trees which were planted for shading purposes in the early ranching years of the monument will be removed from the well/ranch sites where presently found. In these cases, chemical treatment of the stump will be utilized for an effective kill.

No monitoring has been utilized to date, although future removal of specific individuals will be mapped for ease of relocation to determine resprouting potential.

HISTORY AND TREATMENT OF THE SALTCEDAR PROBLEM IN DEATH VALLEY NATIONAL MONUMENT

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ABSTRACT

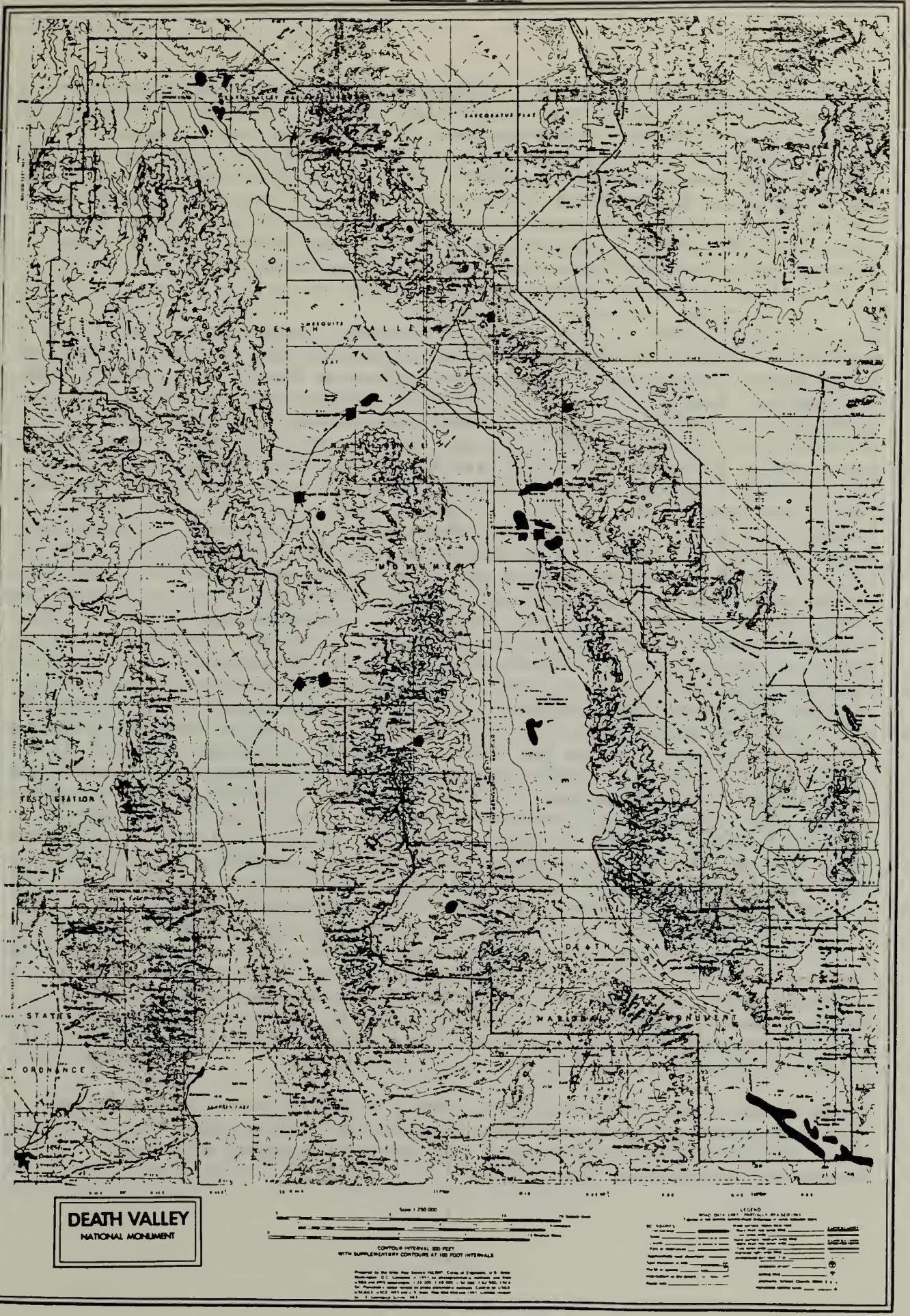
The history of saltcedar (*Tamarix ramosissima* Ledeb.) and athel trees (*T. aphylla* (L.) Karst.), two alien woody plants from the Middle and Far East, in Death Valley National Monument, and efforts to control them, is discussed. Athels were introduced in the early 1930s and possibly in the 20s. Saltcedar was definitely present by the mid-1930s but was undoubtedly in Death Valley much earlier. Saltcedar continues to slowly spread into potential habitat within the monument. Control of saltcedar and athel by mechanical removal occurred as early as the 1940s, but then only to conserve water. The first coordinated removal and herbicide treatment occurred in 1971 at Saratoga Springs. Organized mechanical/chemical control has continued since that time to an extent dependent upon the availability of funding and labor.

HISTORY OF SALTCEDAR IN DEATH VALLEY

Saltcedar (*Tamarix ramosissima*) and athel trees (*T. aphylla*) are well established, though localized, throughout Death Valley at elevations below 5000 feet. At the present time there are about 20 known stands (Figure 1) varying from 0.01 acre to 160 acre with 10 to 40,000 stems per acre (extrapolated) according to Peter Sanchez, Resource Management Specialist, (unpublished), who also estimated that their "invasion" of the monument took place in the 1940s.

One of the earliest collections of saltcedar from the California desert was made by S.B. Parish in 1913 (Robinson 1965). The earliest specimen of saltcedar in the Death Valley National Monument Herbarium was collected in 1937 at Cow Creek by M. French Gilman. Coville (1893) does not mention saltcedar, or tamarisk, in his botanical report of the Death Valley Expedition; however, the purpose of his expedition was to investigate the native flora. He specifically excluded "weeds" from some of his species lists. More importantly, saltcedar is never mentioned in his discussions of wetland or riparian communities. If saltcedar was present in Death Valley at this time, it would have been only as a landscape tree or windbreak which Coville might have ignored.

Figure 1. Distribution of Tamarix spp. in Death Valley National Monument



In discussing the history of Furnace Creek Ranch, Greene and Latscher (1981) state that about 1879, William T. Coleman sent to Italy for gardeners to supervise agricultural development of the site, that at great expense, the soil was "scientifically fertilized" and various types of trees were planted in the resulting dark and heavy loam. Saltcedar as well as athels were certainly available from western nurserymen in 1879, and had been for about 30 years prior to this (Robinson 1965); Italian gardeners would surely have been aware of saltcedar, as *Tamarix* contains several Mediterranean species.

In the early part of the twentieth century, athels as well as perhaps saltcedars may have been planted around various "pioneer" homesteads within what was later to become Death Valley National Monument. A good example is Nevares Springs settled by Adolphus Nevares, a Spanish-American miner/homesteader in 1910. Mr. Nevares and coowner Montillus Beatty established Cow Creek Ranch where they planted a well irrigated garden and "orchard". After Mr. Beatty's death, Mr. Nevares became the sole occupant and in 1908 received title to the 360 acres from the U.S. Government. Fields of alfalfa, vegetables, and melons were grown (Greene and Latscher 1981) and quite probably saltcedars and athels. When the monument was established in 1933, problems arose because the water supplies to the original monument headquarters at lower Cow Creek were controlled by Mr. Nevares. As described in a series of memoranda by then Superintendent T.R. Goodwin (Goodwin 1951a, 1951b) Nevares had diverted large amounts of water from the source springs into a plethora of ditches and channels to irrigate his plantings. Much of this water was lost to evapotranspiration and infiltration. Photographic evidence from 1941 shows well established athels as well as saltcedar at the Nevares homestead and gardens. Close inspection of the photographs leads one to believe that the athels, at least, were planted prior to 1930. After a 17-year off-and-on condemnation suit, the NPS finally acquired the property in 1951. By this time athels and saltcedar were well established on the site. In a memorandum to the Superintendent (Keller 1950), Park Naturalist L. Floyd Keller describes "Athel Tamarisk, *Tamarisk* [sic.] *aphylla*" as being concentrated about the cabin and at the upper and lower portions of a 1 mile by one-eighth mile irrigated strip, but sparsely growing over the entire strip. Similarly, "French Tamarisk, *Tamarisk* [sic.] *gallica*" was also sparsely distributed over the 80-acre strip. Most of the *Tamarix* was purposefully planted by Mr. Nevares as some of the 1941 photos clearly show linear arrays of young cuttings lining the irrigation ditches.

It is also known that the CCC, which worked in the monument in the mid-1930s planted the avenue of athel trees which still lines part of the road leading into the present maintenance and resources management facilities.

Greene and Latscher (1981:739) exhibit a picture dated ca. 1930s of the spring house at Saratoga Springs with what are surely athel trees in the background. Neither Mendenhall (1909) nor Thompson (1929) mention athels or saltcedar in their respective descriptions of Saratoga Springs, but they do mention the native vegetation: "tules" (probably *Typha dominguensis* and *Scirpus* spp.), "Indian Sugar Cane" (probably *Phragmites australis*) and "salt grass" (*Distichlis spicata*). Furthermore, both Mendenhall (1909:20) and Thompson (1929:59), in sections dealing with vegetation as a guide to availability of groundwater, discuss several native plant species indicative of groundwater including mesquite, arrow-weed, yerba mansa, and saltgrass. Athels and saltcedar are not mentioned. The trees at Ibex Springs appear to have been established during the same period since they are approximately the same size as those which used to occur at Saratoga Springs (these were removed in the early 1970s) and Greene and Latscher (1981) state that: "little remained of the (Ibex Springs) mining camp by the time the Ibex Talc mines opened in the mid-1930s." The trees may have been planted by the new operators.

The Eagle Borax Works site is another matter. A large stand of saltcedar and athels was removed from here between 1974 and 1984, but the source of the plants is highly problematic. The saltcedar (or deciduous tamarisk, *Tamarix ramosissima*) was probably established from seed which blew in from sources growing in riparian areas and inland saltmarshes south of the monument. The athels were undoubtedly planted, but when? The Eagle Borax Works operated only between 1881 and 1884. There are some very large stumps at Eagle Borax Works, however, these trees are very fast growing and there is no reason to believe that there are no "false rings" present. Cursory counts of rings on some of the larger stumps reveal an age of around 40-50 years, coincidental with the establishment of trees at other sites in the monument. A story related by Kirby Simms, a monument employee who had worked in Death Valley for over 25 years prior to his retirement several years ago, was that the Superintendent (T.R. Goodwin) caused them to be planted here and elsewhere in the monument (by the CCC?). Photographs taken in 1944 of the Eagle Borax Works show well-established athels about 20 feet or more in height. The trees could easily be 10 years old or older, but were obviously established prior to 1940 and at the latest, the mid-30s (when the monument was established). Trees may well have been planted earlier at this site; a thorough investigation of the remaining stumps by dendrochronological methods may give some indication.

One of the most unusual occurrences of saltcedar in the monument is the 160 acres occupying a series of swales on the northern periphery of the Death Valley Dunes. There is no record of saltcedar here prior to 1968. The winter and spring of 1968-1969 was unusually wet with extensive local flooding, as was the simi-

lar period in 1972-1973. It's my guess that the saltcedar became established at this time and was able to develop sufficiently to tap the groundwater which is within 5-30 feet of the surface here in the Mesquite Flats Sink (Miller 1977). At the present time, this is one of the largest and densest concentrations of *Tamarix ramosissima* in the monument.

The developed area around the Furnace Creek Ranch inholdings held by the Fred Harvey Company has always been a haven for athels and saltcedar, perhaps predating the oldest specimens in other parts of the monument. A thorough investigation may reveal that the original plantings were started by Pacific Coast Borax's Italian gardeners in the 1890s. At the Furnace Creek Inn, saltcedar is trained to a hedge as part of the historic landscaping. Interestingly, there have been numerous reports down through the years of employees of the Fred Harvey Company planting cuttings of saltcedar along the irrigation ditches that flow through their property. No doubt, human intervention has been an important factor in the spread of saltcedar at this location. Unfortunately, because the Park Service has little authority over this private land, and because the current owners have been reluctant to address the saltcedar problem, this source of saltcedar invasion is likely to remain for some time to come.

SUMMARY OF THE HISTORY

Saltcedar was probably present and naturalized in Death Valley prior to 1937, the earliest established date. Evidently, it was not present or was not important enough as a component of Death Valley's wetland flora in 1891 for a trained professional such as Coville to mention it in the annals of his expedition.

Athel trees were planted in the early 1930s and probably prior to that but there is, as yet, no quantitative data to support an early twentieth/late nineteenth century establishment. Then again, there were Coleman and his Italian gardeners, and who knows what "trees" they planted at Furnace Creek Ranch?

RECOGNITION OF THE PROBLEM

The recognition of the *Tamarix* problem in Death Valley National Monument was preceded by a continuing appraisal of the need for phreatophyte (i.e., *Tamarix*) control on a regional level. This appraisal has been ongoing throughout the Southwest since the late 1940s and early 1950s.

According to Culler (1966) and Gatewood et al. (1950) identified saltcedar as one of the most objectionable phreatophytes due to its high water use. In 1960, the Senate Select Committee on

Water Resources reported that there were 667,000 acres of phreatophytes in the Lower Colorado River basin which used 1,200,000 acre feet of water per year (Culler 1966). The Gila River phreatophyte project was established in the mid-1960s under the aegis of the U.S. Geological Survey and cooperating agencies (Culler 1966). Since that time, a great deal of literature on the physiology, ecology, and hydrological relationships of phreatophytes, most notably saltcedar, has been published. Most of this material has been reviewed by DeLoach (1986).

In Death Valley National Monument the first public dissemination of information mentioning saltcedar as a potential threat to park values was in the 1976 Management Options for Natural and Cultural Resources, Death Valley National Monument (NPS 1976), which proposed hand-cutting and treatment with Kuron (2,4,5-TP, now banned by the Park Service) of 200 acres of saltcedar/athel distributed around springs and wetlands throughout the monument. Some removal using Silvex was in fact done. The 1977 Statement for Management does not refer to saltcedar specifically, but does allude to removing the influences of alien plants and animals. The proposed Natural and Cultural Resource Management Plan (NPS 1982) lists saltcedar along with several other alien plants as constituting a threat to the monument's natural resource values and outlines the need for a program of control. The saltcedar control program was outlined in a project statement (DEVA-N-02) and was subsequently funded in 1986 ($42,000) and again in 1987 as part of a Spring Rehabilitation Package (DEVA-N-16) where $25,000 out of $45,000 was set aside for saltcedar control and eradication.

Prior to 1976, the saltcedar issue was monitored largely through the efforts of Peter Sanchez, former DEVA lead interpreter and resource management specialist. He wrote several articles for distribution to the general public. One, "Saratoga Springs Rehabilitation," outlined the rationale and justification for removal of athels and saltcedar at Saratoga Springs (Sanchez 1972a). Another, "Tamarisk Fact Sheet" (Sanchez 1975), summarized current information on the biohydrological relationships of *Tamarix*. Sanchez also organized the first control efforts in the Monument, first at Saratoga Springs in 1971, followed by Eagle Borax Works soon after.

In the 1960s, little seems to have been written about the saltcedar threat in terms of warnings about environmental consequences. An exception was Hunt (1966) who wrote that:

> prior to the introduction of the tamarisk trees the chief plant in these (spring and seep) habitats evidently was honey mesquite. However, the tamarisk is well suited to this environment; it is a salt-tolerant phreatophyte that can be expected to spread to most or all of the marshes around the saltpan.

Writing at the same time, Hunt et al. (1966) estimated water use of saltcedar and athels at Eagle Borax Works over a 240-day growing season as 10 acre feet/acre/year.

Prior to the 60s, little attention seems to have been given to the *Tamarix* issue in Death Valley National Monument.

PAST EFFORTS AT TAMARIX CONTROL

The 40s and 50s: Removal of saltcedar in Death Valley National Monument can be documented as early as 1941 (Grumigen 1941). In order to restore water to the NPS pipeline fed by Nevares Springs, monument staff with the aid of the CCC, and the permission of then property owner Adolphus Nevares, cleaned out water diversion ditches and channels clogged with a "jungle" of vegetation, including saltcedar at a cost of $1,118.00. In 1951, shortly after the Nevares property was acquired by the Park Service, T.W. Robinson, later the author of a somewhat classical article on the saltcedar problem in the Southwest (Robinson 1965) performed an investigation of the water resources of the Nevares property (Robinson 1951). Robinson declared that:

> in places, the vegetation was so dense that it would support the weight of a man, and the writer found it necessary, in a few instances, to cut away the vegetation under his feet in order to determine the location of the channel in which water was flowing.

Two months before Robinson performed his investigation, T.R. Goodwin, then superintendent, ordered the clearing of vegetation (weeds, dried grass, and tamarisk branches) from the numerous ditches and other water diversions that Mr. Nevares had constructed during his ownership. By removing the vegetation and blocking off certain of the ditches, a measurable flow was reestablished for Robinson's investigation (Goodwin 1951c). It is quite likely the monument staff managed vegetation, including saltcedar, in a similar manner at other major domestic water sources within the monument. In the case of Nevares Springs, no mention is made of methods other than mechanical removal. However, it is unlikely that saltcedar was earmarked as a species particularly in need of removal, vegetation in general around these water sources was removed as a means of managing the water supply to maximize flow by eliminating loss via evapotranspiration. Indigent miners still do this in the canyons of the west Panamint Mountains where water sources are diverted for domestic use at millsite claims, etc.; in many cases, large strips of riparian vegetation have been set afire to clear the vegetation.

The 60s and 70s: The first vegetation management project in Death Valley specifically planned to remove *Tamarix* in order to return an area to a more natural condition took place in January 1972 at Saratoga Springs (Sanchez 1972a, 1979). Several athels (*T. aphylla*) were cut, the roots removed with heavy machinery. Small saltcedars (*T. ramosissima*) were handcut; both athels and saltcedars were treated with herbicide (Kuron = Silvex) to prevent regrowth. The athels have never resprouted, but there has been a substantial reinvasion of saltcedar. Saratoga springs has been identified as an area where saltcedar should be eliminated.

The next saltcedar management effort took place between 1974 and 1984 at the Eagle Borax Works Spring, the second largest on the west side of Death Valley. Historically, a series of shallow ponds stood at this site, surrounded by about 40 acres of wetland vegetation including athels, saltcedar, saltgrass, arrow-weed, mesquite, pickleweed, tules, and alkali sacaton. The athels seem to have been introduced in the 1930s (see previous section); it would be speculation to attempt to pin-point the date of the first appearance of saltcedar at Eagle Borax Works. *Tamarix ramosissima* was definitely in the area by 1937 and probably much earlier. According to Sanchez (ca. 1972a), the quickly spreading and heavily transpiring saltcedars as well as the large athels were reducing the water table. By 1950, there was still a pond of several acres; by 1966, the visible discharge of the spring was small (15-25 gal/min) and often fell to zero during the summer months; by 1971 the visible discharge was zero year-round and the pond had completely dried up (Hunt et al. 1966 Sanchez ca. 1972b). Hunt et al. (1966) measured actual discharge of the spring at Eagle Borax Works by estimating on the basis of the evapotranspiration discharge by the plants over a 240-day growing season; the estimated discharge was 300 gallons/minute.

In 1971, members of the park staff attempted to restore the site to its original condition. A "control burn" of 10 acres was made in August 1971. Within 8 weeks the water table had risen 1.2 feet and a pond of 1 acre reappeared.

According to Mr. Ron Cron (personal communication) currently a member of the Death Valley National Monument staff, and a participant in the *Tamarix* removal program at Eagle Borax Works, abatement of saltcedar and athels continued through the 70s and 80s. From 1972 to 1976 all the athels were removed by cutting followed by treatment of stumps with Kuron herbicide. Some stumps were mechanically excavated, followed by direct treatment of roots with herbicide. The trees have been completely eliminated; there is no known resprouting.

The 80s: Kuron and other Silvex-like products were banned in the late 70s so when a large effort was made to eliminate saltcedar

at Eagle Borax Works between 1982 and 1984, Tordon RTU was the herbicide of choice and was used extensively. Although there is occasional reinvasion, which is periodically controlled, all the saltcedar here was eliminated by a combination of mechanical and chemical control, along with occasional burns to eliminate slash and create access. In 1981 one of these fires got out of hand and ended up doing considerable damage to an adjacent mesquite grove. The fire scar is still highly visible.

The removal program here was quite successful. The water table has risen considerably to the extent that several large pools (some well over an acre in extent) have reappeared. The removal is enforced through cyclic maintenance.

Our current removal program began with some confusion in October 1985. The monument received oral approval for expenditure of funds. This approval was rescinded by December after an expenditure of about $42,000 on labor, training, and equipment. However, saltcedar and athels were removed and treated with Tordon RTU on 9 acres of land at the Cow Creek maintenance/ residential area and at Nevares Springs. Funding was renewed in FY87. Approximately sixty-nine man days were spent removing saltcedar and athels. Sixty-five additional saltcedars (*Tamarix ramosissima*) were removed from Nevares Springs, along with the disposal of slash and retreatment of resprouts from the previous year. Perhaps, because of improper treatment, 98% of the athels (*T. aphylla*) cut at Nevares Springs the previous year had resprouted. At Lower Cow Creek, 54% had resprouted.

Several dozen saltcedars were also removed from two backcountry springs: Klare and Monarch Canyon springs

FUTURE GOALS AND OBJECTIVES

Our future plans have been set back because of an unfortunate fire in our pesticide storage building. However, some key objectives are:

1. Obtain proper facilities for storage of hazardous materials.

2. Replenish our herbicide supply, but not to the extent of buying such large supplies at one time. Though not directly affected by the fire, 100 gallons of Tordon RTU were subjected to high temperatures and will have to be returned to Dow Chemical Company. Smaller stocks adequate for a year's removal effort are more manageable and safer to store.

3. Formulate a plan to remove 160 acres of saltcedar which has invaded the north side of the Death Valley Sand Dunes.

4. Assist Dr. Stan Smith, University Nevada Las Vegas in the implementation of a research and monitoring study of saltcedar in Death Valley National Monument.

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STATUS OF TAMARISK AND ITS CONTROL IN GRAND CANYON NATIONAL PARK

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ABSTRACT

There are three areas of tamarisk (*Tamarix ramosissima*) colonization in Grand Canyon National Park: 1) the sandy terraces along the Colorado River, 2) among native riparian vegetation along tributary streams, and 3) along roadsides and in waste areas in Grand Canyon Village. Tamarisk has been present along the Colorado River as scattered individuals for at least 50 years, but has only flourished since the completion of Glen Canyon Dam in 1963. Many benefits of this new riparian vegetation have been identified and the prospects for returning the riparian zone to a natural condition are very remote. Therefore, tamarisk will be allowed to remain a part of the river riparian zone. Though tamarisk invasion is minor along tributary creeks and springs, it will be inventoried and controlled to prevent degradation of water resources and native riparian vegetation. The few tamarisks growing in Grand Canyon Village will be removed.

INTRODUCTION

Grand Canyon National Park is a large natural area where 1.2 million acres of land in northern Arizona are set aside to protect this largest and most famous canyon of the Colorado River. The gorge begins at Lees Ferry, 15 miles (24 km) downstream of Glen Canyon Dam, and extends for 277 miles (446 km) to the Grand Wash Cliffs and the headwaters of Lake Mead. Elevation in the park ranges from 1,220 feet (372 m) to over 9,100 feet (2,774 m). This range in elevation and its associated climatic variation supports a wide variety of biotic zones, from lower Sonoran along the Colorado River to Canadian on the Kaibab Plateau.

The exotic shrub tamarisk (*Tamarix ramosissima*, though other species of *Tamarix* might also be present) has invaded a surprisingly wide range of habitats in Grand Canyon. The areas of tamarisk colonization can be divided into three groups. By far the most extensive tamarisk growth occurs along the Colorado River. Tamarisk also grows along most of the tributary creeks, but its

occurrence is much more scattered than along the river. The third area of tamarisk colonization is along roadsides and in waste areas in Grand Canyon Village. Each of these areas offer different opportunities for management and control.

TAMARISK ALONG THE COLORADO RIVER

Tamarisk (saltcedar) was first reported along the Colorado River in the period 1933 to 1938 near the confluence with the San Juan River (Woodbury and Russell 1945). During the following 30 years tamarisk became widespread along the river but it was limited in abundance to isolated plants (Turner and Karpiscak 1980). This was apparently due to the lack of stable unoccupied habitat. Stable habitat was provided by the closing of Glen Canyon Dam in 1963. Sediment terraces that were previously inundated and reworked by each spring runoff were then available. Isolated plants already growing along the Colorado River provided a seed source that allowed tamarisk to be one of the first colonizers on the previously barren terraces.

Native species including coyote willow, *Baccharis* sp., arrow-weed, honey mesquite, and catclaw also colonized the terraces (Stevens 1985). A mosaic of plant species developed that included large monotypic thickets of tamarisk, coyote willow, and arrow-weed. Mixed communities also developed and in some instances native species were supplanting tamarisk (Brian 1982).

Despite the fact that exotic tamarisk is a major component, this new riparian vegetation created habitat for many native wildlife species. Several species of birds and reptiles are now found on these once barren beaches (Carothers and Johnson 1981). Bank dwelling beavers are now also common throughout the canyon wherever large sandy terraces remain. All of the phreatophyte vegetation on these terraces provides some bank stabilization. The new riparian vegetation, and primarily tamarisk, also provides recreational boaters with a welcomed respite from the summer sun.

These numerous benefits have left park managers with a challenge: namely, reconciling the obvious benefits of this unnatural riparian vegetation that is a result of an artificial flow regime, with the Park Service mandate to preserve natural ecosystems. At this time the Colorado River is managed as a naturalized ecosystem with a goal of maximizing the benefits that this system provides. This decision was made in recognition of the practical impossibility of returning the Colorado River to a natural condition. The increasing rarity of healthy riparian systems in the desert Southwest was also a major consideration.

The National Park Service has no plans at this time to attempt to control tamarisk along the Colorado River in Grand Canyon. In the future there may be opportunities to institute flow regimes or biological controls that will favor native species over tamarisk. Even if these are successful, tamarisk will probably be a major component of the Colorado River ecosystem for the foreseeable future.

TAMARISK INVASION OF TRIBUTARY CREEKS AND SPRINGS

Tamarisk has spread from the Colorado River to many of its tributary creeks and springs. It is widely distributed but consistently makes up only a minor component of the riparian vegetation. Monotypic stands of tamarisk have not been observed along these creeks.

There are two major concerns about the invasion of tamarisk in small creeks and springs. If native plant species are replaced by exotics, the productivity and desirability of the riparian zones may be reduced for several native species. A heavy invasion of tamarisk in small water sources could reduce the amount of water available or dry it up entirely. Many small creeks and seeps are kept relatively free of riparian vegetation by highly saline waters and frequent floods. Tamarisk is very salt tolerant and may be more able to tolerate periodic flooding than native species.

The park plans to control tamarisk along creeks and near springs. The first step in this program will be an inventory of the extent of tamarisk invasion. Problem areas can then be prioritized and a control program initiated.

Treatment areas will consist of individual watersheds. Once it is eliminated from a watershed the only direct avenue for tamarisk reinvasion will be up from the Colorado. A long-term maintenance program will be needed to prevent reinvasion. Depending on the size of the control and maintenance programs, control will be accomplished by a seasonal work force or backcountry rangers on patrol.

TAMARISK IN GRAND CANYON VILLAGE

Several tamarisk plants have become established along roadsides and in waste areas in Grand Canyon Village. These plants are vigorous even though they are growing at 7,000 feet (2,160 m) in elevation. No records can be found to indicate when they were planted. The largest tamarisks appear to be 15 to 20 years old. From their location, it appears a few of the tamarisks were intentionally planted as part of the landscaping around some lodges.

An inventory in 1986 identified 22 tamarisk in the village area (8 russian olives, 2 peaches, and an elm were also inventoried). These tamarisks are the park's first priority for control because of the manageable size of the problem, the completed inventory, and ease of accessibility. The treatment planned will consist of cutting to remove brush, making a fresh cut at the root crown, immediately followed by stump treatment with Garlon 3A. The U.S. Magistrate has included tamarisk removal as one of the community service projects that offenders will be sentenced to. Follow-up surveys will be necessary to detect resprouting or plants that were missed in the initial inventory and treatment.

CONCLUSION

A balanced approach to tamarisk management is needed at Grand Canyon National Park. Available resources and control techniques, the benefits and environmental damage caused by tamarisk, and the management direction will all be considered in planning a control program.

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SUMMARY OF TAMARISK CONTROL EFFORTS IN CANYONLANDS AND ARCHES NATIONAL PARKS AND NATURAL BRIDGES NATIONAL MONUMENT

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ABSTRACT

Tamarisk (*Tamarix ramosissima*) has become established extensively in Arches and Canyonlands National Parks and Natural Bridges National Monument during the last 30 to 50 years. The invasion is most dramatic along the corridors of the Green and Colorado Rivers in and adjacent to Arches and Canyonlands where it has stabilized once ephemeral sandbars with dense homogeneous stands. This invasion along 15-20% of the corridor appears to have caused channelization of the rivers and subsequent aquatic and terrestrial ecosystem alteration. This exotic plant has also become established in most springs, seeps, and washes, often competing with native species and reducing water availability to wildlife, native vegetation, and recreationists.

INTRODUCTION

Canyonlands and Arches National Parks and Natural Bridges National Monument are located in southeastern Utah on the Colorado Plateau. All three of these areas are administered under a general superintendent in Moab, Utah. This area is characterized by dramatic sandstone geology intricately eroded into a network of canyons, cliffs, mesas, and expansive slickrock. Arches National Park and Natural Bridges National Monument are especially noted for the unusual rock arches and bridges which have been weathered out of sandstone walls and spires. The Colorado River borders the east and south boundary of Arches National Park and joins the Green River in the heart of Canyonlands National Park. The elevation of these parks ranges from approximately 4,200 to 7,000 feet, and vegetation and wildlife vary accordingly. Dominant vegetation types include pinyon-juniper; perennial grasslands of Indian ricegrass (*Oryzopsis hymenoides*) and needle and thread grass (*Stipa comata*); mixed shrublands of sagebrush (*Artemesia tridentata*), fourwing saltbush (*Atriplex canescens*), and Mormon tea (*Ephedra viridis* and *torreyana*); monotypic stands of blackbrush (*Coleogyne ramosissima*); greasewood

(*Sarcobatus vermiculatus*) dominated shrub zones; and riparian areas inhabited by willow (*Salix exigua*), cottonwood (*Populus fremontii*), and tamarisk (*Tamarix ramosissima*). Average annual precipitation in Arches and Canyonlands National Parks is 8-11 inches, while Natural Bridges National Monument receives 12.5 inches per year. The greatest stress to plants in this region occurs during the hot dry period from May until August.

Tamarisk control efforts began at Natural Bridges National Monument in 1958 where it was simply pulled out of the ground by hand. This kept the plant invasion relatively low for some years, but the effort dropped off during the 70s allowing for some reestablishment in the monument. During 1985-1987 tamarisk has been close to eliminated in Natural Bridges National Monument as part of the renewed effort toward reducing this species. Control projects in Canyonlands and more recently in Arches have focused on water sources and areas of special importance to recreationists and wildlife. In Horseshoe Canyon in Canyonlands and Natural Bridges National Monument, cottonwood regeneration appears to have increased where tamarisk has been controlled. More monitoring of control effects is proposed, but depends on funding. During the summers of 1983-1985, Tordon RTU was applied immediately to cut stumps to kill tamarisk plants. This was found to be approximately 50% effective, but use of this herbicide was stopped and replaced by Garlon 3A due to Tordon's 2-4-D chemical composition, relatively long half-life, and higher toxicity to the environment compared to Garlon. Effectiveness of Garlon, compared to Tordon, has yet to be quantitatively evaluated, but it appears to be less effective. We hope to evaluate this further. Some burning was conducted in areas along the Green River where it was speculated that high water might scour away remnants of burned tamarisk. This was not successful due to low water flows.

Historical photographs of the Colorado Plateau region show that tamarisk spread from northern Arizona to the upper reaches of the Colorado and Green rivers at a rate of about 20 km/yr. Tamarisk has spread into most tributaries and across mesa tops anywhere there is water.

Tamarisk has invaded all three of these units extensively, particularly along the banks of the Colorado and Green rivers in Canyonlands and Arches national parks where it grows in dense homogeneous stands. It has also grown into the majority of springs, seeps, and potholes (where a substrate is present), as well as perennial and intermittent drainages in all of the national park system units.

The last vegetational study along the rivers in Canyonlands was done by William Graf in 1976. His work dealt with the changes that have taken place from the invasion of saltcedar (*Tamarix*

ramosissima) along the Green River. His investigations found that tamarisk invaded Canyonlands from the south between 1925 to 1931. Graf's work also documented that saltcedar has channelized the Green River causing a 27% reduction in river width. This has made over-bank flow more likely even from modest discharges. He estimated 9,600 acre feet of water is transpired by tamarisk each year along the 90-mile stretch of the Green River between Green River, Utah, and the confluence with the Colorado River (Graf 1976).

As previously stated, tamarisk along the Green and Colorado rivers occurs in stands that appear to be nearly pure. The tamarisk stands are not continuous but rather alternate with other riparian or floodplain species including sandbar willow (*Salix exigua*), New Mexico forestiera (*Forestiera neomexicana*), cottonwood (*Populus fremontii*), box elder (*Acer negundo*), oak (*Quercus gambelii*), fourwing saltbush (*Atriplex canescens*), greasewood (*Sarcobatus vermiculatus*), phragmites, and bare rock or cliff.

Along the river corridors it appears that tamarisk alone colonizes new sandbar accumulations. In some cases sandbars, after a season's highwater flow, are covered with tamarisk seedlings only to be washed away in the next year's highwater flow. If highwater flow is not sufficient to wash the bars away, tamarisk takes hold and subsequent highwater cannot dislodge the larger plants. Graf (1976) observed some instances in which willow successfully out-competed tamarisk, but these cases seem rare.

Because of a lack of information on tamarisk distribution, a study was made by Resource Specialists Jeff Connor and Katherine Kitchell in 1983. The results of that study, which will be reconducted on a 5 to 10-year cycle, are summarized in Table 1.

TAMARISK CONTROL IN NATURAL BRIDGES NATIONAL MONUMENT

Tamarisk control in Natural Bridges National Monument is proceeding successfully. Begun in 1958, tamarisk was hand-cut and burned without the use of herbicides. The trees resprouted as evidenced by the finding of large cut stumps when tamarisk is removed today. When key people transferred, there was no removal work for a period of 10 years between 1975 and 1985. Removal began again in 1985 and by 1987 is considered 90% successful. Occasionally tamarisk plants are still found in the canyon. The Bureau of Land Management (BLM) has created several water impoundments in dry washes around the monument. These impoundments are choked with tamarisk, providing a seed source, as does White Canyon above and below the monument. Natural Bridges National Monument is a small enough area, 7,435 acres, that an aggressive removal program should be able to keep the

Table 1. Frequency, mean height, and canopy cover for the dominant plant species along the Green and Colorado rivers.

	Frequency (%)	Height	Canopy Cover (%)
Green River			
Tamarisk	35.38	5.86 m	22.34
Willow	17.54	3.90 m	9.73
Forestiera	12.00	3.25 m	8.20
Colorado River			
Tamarisk	14.32	4.96 m	6.07
Willow	15.50	4.25 m	7.80
Forestiera	21.34	2.83 m	16.83

monument free of tamarisk. The use of herbicides is a concern the Unit Manager would like to reduce as much as possible.

TAMARISK CONTROL IN CANYONLANDS

Canyonlands recognized the tamarisk problem and wrote an action plan for tamarisk removal in 1977. This plan called for removal in well-defined areas such as springs, and smaller canyons where control is feasible.

In 1977, tamarisk removal was begun in the Horseshoe Canyon detached unit west of the park. Three months were spent on the program in 1977. Since 1983, a few days were spent each year cutting and treating tamarisk with Tordon RTU or Garlon 3A on a maintenance basis. There remains work for a crew for a week or two to remove existing tamarisk in Horseshoe Canyon. Without active annual maintenance, the canyon would again become choked to the 1977 level or worse. Seed germination is very high with thousands of seedlings sprouting each year in the wash bottom. Summer flash floods are depended on to remove these seedlings. The return of cottonwood trees appears to be correlated with the tamarisk removal as well as the elimination of grazing in 1983. Most new cottonwoods in Horseshoe are less than 10 years old and there are stands of 8- to 10-year-old trees.

Other work in Canyonlands has been scattered, with rangers cutting tamarisk from isolated springs or removing single trees growing in remote locations. Work in Lathrop Canyon was done by cutting without using herbicide. Regrowth completely negated the work by the following fall. Portions of Lathrop and Shafer Canyon have been cut and treated and are on a maintenance basis. Two areas along the Colorado and Green rivers were selected for experimental treatment in the spring of 1985. With heavy snowfall in the mountains, heavy spring runoff was expected. Isolated sandbars that had become stabilized by tamarisk were selected for treatment. The stands were burned in the early spring with the expectation that high water could wash out the sandbars if the mass of vegetation was removed. Spring snowmelt was slow and gradual and did not result in water levels high enough to flood the sandbars and no results were obtained. The tamarisk has since sprouted vigorously.

FUTURE CONTROL EFFORTS

In Canyonlands and Natural Bridges, maintenance of cleared areas must continue. Rangers are encouraged to remove isolated trees on an opportunity basis.

Arches is proposing to remove approximately 3 acres of tamarisk along a narrow wash. The purpose of this removal is to revive a spring and hopefully provide year-round surface water as well as restore native vegetation. The plan is to first burn the thickets, protecting the few cottonwoods by mechanical removal of tamarisk in their vicinity. The remaining stumps would be cut and treated with Garlon. Cuttings from cottonwoods on site would be planted to facilitate restoration of native vegetation. A few local environmentalists have taken exception to the proposal and enlisted the aid of Edward Abbey and the media to publicize their opposition. As a result, an Environmental Assessment was prepared. Tamarisk removal at the Salt Wash Spring is not currently scheduled. Removal could take place either in the spring or fall of 1988.

PROPOSALS FOR THE FUTURE

Without more people and money to work on tamarisk it is unlikely large projects will be undertaken. The Canyonlands group parks have all that can be handled with a yearly maintenance program, with the present staff. We need to determine the effectiveness of Garlon 3A to make sure we are achieving satisfactory results per hour of work. We need to update the Tamarisk Removal Action Plan to effectively use our limited resources to insure cleared areas are maintained and to identify new areas that have high priority for clearing. A priority list of new areas needs to be based on:

1. Our ability to do the initial work and maintain the area every year.

2. What will we achieve of benefit to the park by clearing a specified area (e.g., restore waterflow in springs for wildlife and visitors, restore native habitats)?

The thickets along the river can be expected to increase in both areas and density. River running is a major activity in the park and a major economic activity for Moab. The thickets may eventually choke campsites causing overcrowding and friction at the few campsites remaining open. The park may be forced to hire crews to clear these areas. Perhaps river runners will be assessed a $5 fee to pay this expense.

The possibility of having biological controls could play an important role in our future strategy. Dr. Tim Graham has researched the effects of grasshoppers (*Schistocera shoshone*) and a leaf hopper (*Opsius stactogalus*) on tamarisk. Although the trees are stressed, they retaliate and apparently have no long-term ill effects. An effective biological control appears to be the only effective solution to the large scale tamarisk problem along the river and in major washes, but the environmental impacts of such control must be assessed in great detail prior to initiation of biological control.

Research Papers Presented at the Tamarisk Conference

ECOLOGY AND MANAGEMENT OF RIPARIAN BREEDING BIRDS IN TAMARISK HABITATS ALONG THE COLORADO RIVER IN GRAND CANYON NATIONAL PARK, ARIZONA

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ABSTRACT

The density, diversity, and ecology of riparian breeding birds in tamarisk habitats vary widely throughout the southwestern United States. Avian density and diversity in tamarisk on the lower Colorado River is relatively low, while the opposite is true along the upper Colorado River in Grand Canyon National Park. Suggested reasons for these differences are presented from the literature, which are primarily biogeographical considerations and climatic gradients. If avian use of tamarisk is subject to biogeographical variation, then regional strategies for the management of tamarisk as avian habitat need to be developed. Tamarisk in its present condition along the Colorado River in Grand Canyon National Park provides an important resource to nesting riparian birds, and should be recognized and managed as such.

INTRODUCTION

Riparian habitats dominated by tamarisk (*Tamarisk ramosissima*) are among the most abundant and widespread vegetative communities available to low-elevation riparian breeding birds in the southwestern United States (Hunter et al. 1985). Avian breeding ecology in tamarisk communities has only been studied extensively along the lower Colorado River. There, tamarisk occurs in a different growth form than is found at higher elevations on the upper Colorado River. Research findings on breeding bird density, diversity, and ecology in tamarisk from the upper and lower Colorado River and other areas of the Southwest are contradictory with respect to the usefulness of tamarisk to breeding birds. These contradictory findings may indicate that different regional management strategies for tamarisk as avian breeding habitat are desirable. The purpose of this paper is to outline some of the regional differences between avian use of tamarisk and to suggest strategies for the management of tamarisk as breeding bird habitat based on these differences. Tamarisk was apparently present in small numbers in the riparian zone of

the Colorado River through Grand Canyon National Park by 1919, when the park was established. Tamarisk was well-established along the river, though still in relatively small numbers, by 1938-1939 (Clover and Jotter 1944). Controlled riverflows resulting from the construction of Glen Canyon Dam in 1963 altered riparian conditions to the extent that tamarisk was able to colonize the predam scour zone in large numbers. Tamarisk was the dominant woody riparian plant along the river by the mid-1970s (Turner and Karpiscak 1980), and remains dominant today. However, a series of large water releases and unprecedented fluctuating flows from Glen Canyon Dam since 1980 have greatly reduced the extent of tamarisk along the river (Pucherelli 1987).

ECOLOGY OF RIPARIAN BREEDING BIRDS IN TAMARISK: A SUMMARY

Avian density and diversity in tamarisk communities vary widely throughout the Southwest. The number of bird species and individuals in tamarisk habitats along the lower Colorado River is significantly lower than avian density and diversity in native riparian communities dominated by either mesquite (*Prosopis* spp.) or cottonwood (*Populus fremontii*) (Anderson et al. 1977; Cohan et al. 1979). In contrast, tamarisk communities exhibit avian densities and diversities as high or higher than native riparian communities along the upper Colorado River in Grand Canyon (Brown 1987a) and along the Pecos River and Rio Grande of Texas (Hunter et al. 1985 Hunter et al. 1988).

Hunter et al. (1985, 1988) have identified the primary reason why such striking regional differences exist between avian use of tamarisk throughout the Southwest. Biogeographical considerations, specifically elevational and climatic gradients, are their suggested reasons for the phenomenon. Elevational gradients from east to west (and north to south) in the Southwest may affect avian use of tamarisk habitats. Elevation declines from east to west and from north to south, so that mean summer temperatures are higher to the south and west: the lower Colorado River represents the most extreme summer environment. Hunter et al. (1988) argue that species which are migratory, midsummer breeders may be unable to use tamarisk that do not provide multi-layered foliage which favorably modifies (cools) local climatic conditions during the summer. Some species nesting in tamarisk at low, hot elevations, therefore, would expose their eggs to heat stress, killing some, greatly lowering their reproductive success, and possibly become unable to maintain a breeding population in the tamarisk community.

Research on avian use of tamarisk communities along the upper Colorado River in Grand Canyon National Park has shown that tamarisk can support a greater density of breeding birds than

native riparian communities. Brown (1987b) demonstrated that avian density in tamarisk (with a mean of 610 pairs/40 ha) was significantly greater than avian density in native mesquite (with a mean of 449 pairs/40 ha). Absolute bird diversity in both communities was similar, although species composition differed substantially. More obligate riparian birds, those that require dense riparian habitat in which to nest in the Southwest (Johnson et al. 1977), occurred in the tamarisk community. Five of six species of obligate riparian birds significantly preferred tamarisk as a nest site over native riparian vegetation. Willow Flycatcher (*Empidonax traillii*), a *de facto* endangered species in the lowland Southwest (Unitt 1987), showed a significant trend of increase over the last 6 years that was strongly correlated with its preference for tamarisk as nesting habitat (Brown in press).

DISCUSSION

If avian use of tamarisk is subject to biogeographical variation, then regional strategies for the management of tamarisk as avian habitat need to be developed. Higher elevation tamarisk communities on the upper Colorado River appear to be more useful to breeding birds than lowland tamarisk communities on the lower Colorado River, a pattern that is in need of confirmation through additional research. Different management strategies appear valid for tamarisk communities on the upper Colorado River, especially considering that tamarisk there is not displacing native vegetation as it is on the lower river. Tamarisk on the upper river has only developed in the last two to four decades in the formerly bare scour zone that was maintained by the large floods that occurred before large dam construction.

Tamarisk communities in certain situations have great value as breeding bird habitat. Therefore, tamarisk control measures based on the assumption that tamarisk was poor wildlife habitat and was displacing native vegetation would be inappropriate (for example, see Kerpez and Smith 1987). Regional strategies need to be developed for the management of tamarisk, but additional research is first needed to further define the patterns of biotic density and diversity in tamarisk communities of the Southwest.

STRATEGIES FOR THE MANAGEMENT OF TAMARISK FOR RIPARIAN BREEDING BIRDS IN GRAND CANYON

Three reasons appear to explain why tamarisk along the Colorado River in Grand Canyon is so useful to riparian breeding birds: 1) the area is higher in elevation and there is less heat stress to nesting birds, 2) the tamarisk community has only developed since 1963 and is in a relatively young stage of vegetative development, and 3) a diversity of different structural habitats

within the tamarisk community is present. Future park management can actively influence the second and third reasons via controlled water releases from Glen Canyon Dam, providing for continued high avian density and diversity along the river.

In general, water releases from Glen Canyon Dam must meet three long-term criteria in order to attain the goal of continued high avian density and diversity in the tamarisk community. These criteria affect primarily the tamarisk plant community, since it is the nature of the plant community that has the greatest effect on the breeding bird community. The water releases must be managed in such a way as to: 1) minimize streambank erosion and subsequent habitat loss, 2) maintain adequate soil fertility levels in the riparian zone for a continued high level of productivity, and 3) maintain the diversity of structural habitats within the tamarisk community.

Streambank erosion in the river corridor has greatly reduced the overall density of breeding birds in the riparian zone since 1980, primarily due to the devastating effects of the 1983 highwater release. When streambanks are eroded away, the riparian vegetation rooted in them is also lost, reducing the amount of potential habitat available to birds for breeding, and eventually reducing the population density of some breeding species.

The role of soil nutrients and how they affect plant and animal productivity in regulated-discharge riverine systems is poorly understood. However indirect the relationship, avian density and diversity in the tamarisk community are linked to the nutrient levels present in riparian soils along the river. Much of the riparian soil upon which plants, and ultimately birds, rely is relictual in nature, deposited in place before the construction of Glen Canyon Dam. Management of the flows from Glen Canyon Dam should take into account the need to avoid fluctuating flows which would leach nutrients from the riparian system, and, if possible, favor flows which could replace or restore nutrients to the riparian zone. The latter could be accomplished through highwater releases during the monsoon season of August and September which would facilitate the placement of floodwater sediments onto the riparian zone.

The present riparian community which supports such a high avian density and diversity is a diverse, structurally-heterogeneous plant community. Nonfluctuating, or steady, flows within a narrow range over a long period of time (30+ years) would tend to reduce the structural diversity of the tamarisk habitats by creating a largely even-aged community. This would, in turn, reduce long-term avian density and diversity. Flood releases from the dam at intervals of no more than one every 20-30 years would provide the disturbance necessary to create a patchy, variably-aged tamarisk community. However, floods such as the

one which occurred in 1983 carry other risks, such as accelerated loss of soil nutrients, temporary loss of certain critical avian habitats such as marshes, and temporary decline in the extent of tamarisk.

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SALTCEDAR EVAPOTRANSPIRATION AND ITS MEASUREMENT

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ABSTRACT

The Bowen ratio technique for evapotranspiration (ET) offers advantages of precision and mobility when compared to traditional water budget methods. This paper describes Bowen ratio energy budget (BREB) measurements of ET from a dense stand of saltcedar (*Tamarix chinensis* Lour.) on the lower Colorado River about 50 km south of Ehrenberg, Arizona, and Blythe, California. ET measurements were made for periods of 2 to 4 days each on 8 expeditions during the 1980 and 1981 growing seasons. Measured daily ET ranged from about 2 mm/day in spring and fall, up to 13 mm/day in midsummer. Growing season ET (233 days, March 23-November 11) was estimated from BREB measurements as 1677 mm, including 42 mm for average summer precipitation. The relatively few BREB data were used to derive a local calibration function for the Penman equation. The function substantially improved Penman estimates of actual ET from the saltcedar, using routine climatic data available at Blythe, California.

INTRODUCTION

The transpiration of water by wildland vegetation is a well-studied process in the southwestern United States, as reduction of transpiration losses could augment presently limited water supplies. Much of the early research on saltcedar water use and management possibilities is nicely summarized by Horton and Campbell (1974). The possibilities for direct control of transpiration and evaporation losses (evapotranspiration, ET) by elimination of riparian vegetation are now recognized as being rather limited. It appears more likely that riparian communities will be managed to maintain a desirable mix of species suited for a variety of purposes, including the augmentation of water supplies. There are surprisingly few ET studies available that are precise enough for use in predicting the water use from various riparian communities. Most measurements of phreatophyte ET have been based upon the water budget, which is a rather insensitive method of estimating ET because of difficulties in estimating soil moisture, especially when roots reach the water table as is generally the case in riparian vegetation. It is

also difficult to extrapolate lysimeter measurements of ET out into the surrounding vegetation.

Newer ET measurement techniques offer advantages over the traditional water budget approach. The Bowen ratio energy budget (BREB) method, which estimates ET from an evaluation of the various flows of thermal energy to and from the canopy, is becoming recognized as a practical alternative to water budget analyses of ET. The BREB method offers potential advantages of sensitivity and mobility, and has a sound theoretical basis. This report describes the application of the BREB method to a stand of saltcedar, and summarizes the results which were obtained periodically throughout two successive growing seasons. It also identifies a number of interrelated publications on the Bowen ratio, some of which have limited distribution.

STUDY AREA

The primary study area was on the Cibola National Wildlife Refuge in the floodplain of the Colorado River at an elevation of 90 m above sea level, and about 50 km south of Ehrenberg, Arizona and Blythe, California. This is the warmest, driest region of Arizona. May through September daily air temperature maxima at Ehrenberg for the period 1941-1970 (Sellers and Hill 1974) averaged 39.5 °C (103 °F), and the mean precipitation total for these five months was only 3.2 cm (1.27 in). High water tables, dense vegetation, intense heat and low humidities combine to produce exceptionally high ET rates throughout this region. The measurements were made near the western edge of a vast saltcedar (*Tamarix chinensis* Lour.) thicket of approximately 10 km² in area. The saltcedar stand was about 7 m high, and the canopy was closed and for the most part rather uniform. Fetch across the saltcedar to the desert was about 1 km to the north and west, and 2 km to the east and south. The floodplain soils were sandy and deep at this site, and the depth to water remained relatively constant at about 3.3 m throughout the two successive summers of measurement.

METHODS

The flows of thermal energy are more easily measured at many evaporating surfaces than are the flows of water and vapor. The processes are well known and described in many texts (see, for example, Oke, 1978). The major energy flows are net exchange of radiation (Q), change of stored thermal energy in soil and vegetation (G), sensible heat exchange between the canopy and the atmosphere (H), and the latent heat associated with the change of state of water between liquid and vapor (LE). These components make up the surface energy balance which always equals zero,

$$Q + G + H + LE = 0 \qquad (1)$$

given the convention that fluxes of energy are positive when to the surface and negative when away. The components of Eqn. 1 are actually flux densities, with units typically being given as [J/m^2].

In the field, the net radiation and the soil heat flux terms are first measured directly with commercial sensors. LE and H can then be expressed in terms of measured temperature and vapor concentration gradients in the air just above the canopy if Eqn. 1 is first divided through by LE, and then solved to yield the BREB model (Bowen 1926) where AP is the psychrometric constant,

$$LE = -(Q + G)/(1 + ß) \quad (2)$$

with ß (Bowen's ratio) given as

$$ß = H/LE = AP\ (dT/de) \quad (3)$$

with A = 0.00065/°C and P (mb) being atmospheric pressure at the measurement site (AP = 0.66 mb/°C at sea level), and dT/de is the ratio of the gradient of potential temperature to that of vapor concentration, measured over the same height dz in the air just above the transpiring canopy. The gradients are typically measured over a height dz of about 0.5 to 1.0 m for crops, and 1 to 3 m for forests. The gradients are small and precise measurements are needed to evaluate LE with Eqns. 2 and 3. Gay (1985a) describes a step-by-step Bowen ratio analysis in sufficient detail to allow a user to apply the method without the need of numerous references. The example data is drawn from a series of field measurements carried out over saltcedar at a site on the Rio Grande near Bernardo, New Mexico.

The BREB equipment used for a series of phreatophyte ET studies was described by Gay (1979); it consisted of a set of specialized sensors, a data acquisition system and a microcomputer. The original design of the Arizona ET (AZET) system was powered by a portable generator; an improved, battery powered design is now available (Gay 1988). The key sensors in the AZET system are unique psychrometers which combine together a ceramic wetbulb element, high output resistance thermometers and a new signal circuit to yield exceptionally precise measurements of temperature and humidity gradients (Hartman and Gay 1981). The psychrometers are used in pairs to measure the vertical gradients of temperature and vapor concentration. The accuracy of the gradient measurements is enhanced by an unusual exchange mechanism which interchanges the pair of psychrometers between readings to eliminate small biases may exist between sensors (Gay and Fritschen 1979a).

The AZET system samples data with a high quality digital data logger and a microcomputer that transforms, analyzes and stores the data, and prints the results for real-time examination. The

BREB analysis of ET is completed every 12 minutes and these values are combined to yield hourly and daily totals of LE. In the saltcedar study, the system was operated with two separate sets of Bowen ratio sensors simultaneously, and their agreement monitored to insure proper operation. The generally accepted precision of water budget ET, or of BREB ET measured elsewhere, is about 15 to 20 percent. This system, however, can detect differences as small as 0.5 percent in the ET rates from two adjacent, irrigated fields (Osmolski and Gay 1983).

RESULTS

The ET measurements were obtained for periods of 2 to 4 days duration on each of 8 separate expeditions to the Colorado River floodplain site during the growing seasons of 1980 and 1981. The results are described in detail by Gay[1] and summarized by Gay (1985b). Daytime data (periods of positive net radiation) were obtained for 21 complete days, and nighttime data for 11 nights. The daytime water use ranged from about 2 mm/day in the spring and fall, up to about 12 mm/day in midsummer, while night losses were quite small, ranging from less than 0.1 mm/day up to about 0.6 mm/day in midsummer. The night data were interpolated to obtain 21 sets of 24-hour totals.

There are two ET estimates, one from each of the two Bowen ratio masts, for each of the 21 days. The two ET estimates differed by about 5 percent on a daily and a seasonal basis, and this difference remained during several runs in which the sensors were interchanged between sites, thus confirming that the difference was site related, rather than instrumental. The two estimates at each site were then averaged to yield the best estimate of saltcedar ET and then the daily values within each run were averaged to further reduce the variation. These values, some from 1980 and some from 1981, are plotted in Figure 1 over the course of a single growing season.

Saltcedar is dormant along the lower Colorado River during the winter season, and the spring green up and the fall dormancy dates were set as March 23 and November 11 after inspection of the site and trends evident in the measurements. The length of the growing season is estimated to be 233 days. A simple trapezoidal integration of the ET curve in Figure 1 yields a total ET of 1637 mm for the 233 day growing season. Of this total, 1548 mm was lost during the daylight hours, and 89 mm at night. Since no storms occurred during the BREB measurement

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[1]Gay, L. W. The Efforts of Vegetation Conversion upon Water Use by Riparian Plant Communities. Research Project Completion Report B-084-ARIZ, U.S. Department of Interior. January 1984.

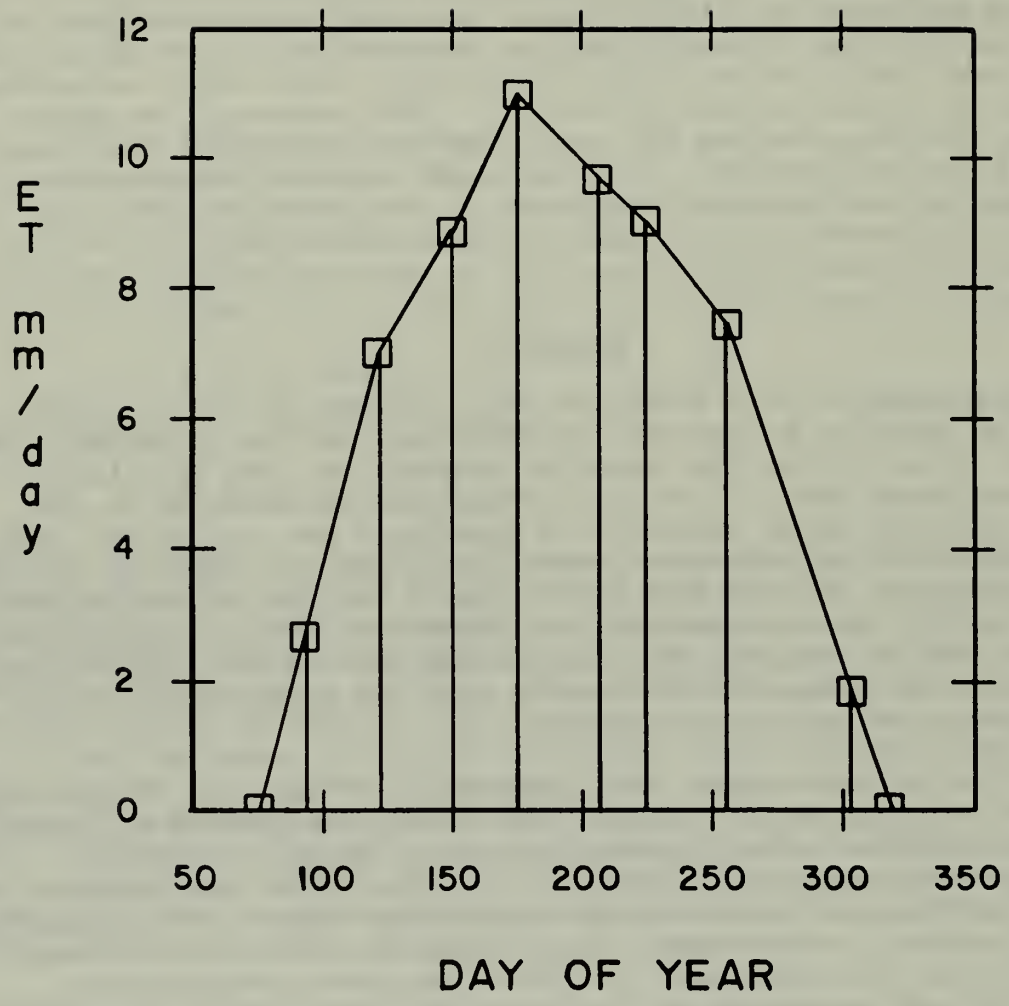

Figure 1. Mean daily saltcedar ET on the lower Colorado River.

periods, the seasonal estimate of 1637 mm should be increased to account for precipitation that might be received. The mean annual precipitation at Ehrenberg, 50 km to the north, is 90 mm, with a bit less than half of that total falling with the 233 day growing season. If all of the limited precipitation that falls at this site evaporates, then the BREB estimate of growing season ET should be increased by 42 mm and the annual ET by 90 mm. The best estimate of saltcedar ET at this site, assuming average precipitation, thus becomes 1677 mm for the growing season, and 1727 mm for the year.

DISCUSSION

There have been only a few attempts to estimate saltcedar evaporation with the BREB method, and measurements summarized above yield what appears to be the only seasonal estimate to be developed from this technique. Gay and Fritschen (1979b) earlier found good agreement of saltcedar ET estimates from constant level lysimeters and the AZET Bowen ratio system at Bernardo, NM. The measurements extended over 5 clear, hot, mid-June days, and mean BREB ET of 8.2 mm/day compared nicely with mean lysimeter ET of 7.9 mm/day.

Gay and Hartman (1981) found that the midsummer ET from irrigated alfalfa was about the same as that from the Colorado River saltcedar site when the climatic conditions were similar (10.5 mm/day for alfalfa, versus 9.3 mm/day for the saltcedar). They used the same AZET BREB system in these measurements, but the two sites were widely separated.

Substantially less effort is required to collect routine climatological data than to obtain and analyze the relatively complex BREB data. Gay (1986) used the Colorado River saltcedar BREB measurements to develop a local calibration function for predicting actual evapotranspiration (AET) from potential evapotranspiration (PET) estimates obtained with the well-known Penman equation. The analysis used climatic data from the Blythe, CA, airport, 50 km north of the saltcedar site to estimate PET for the small number of days when Bowen ratio ET was available from the saltcedar. A 4th-order regression function was developed to correct the PET totals to the AET totals for the saltcedar, with $r^2=0.92$ and MSE=1.46. The improvement in prediction was dramatic. The uncalibrated Penman model, run with Blythe data for each day, predicted 2475 mm of growing season PET; the calibrated Penman model, again run on each day, predicted 1726 mm of growing season AET from the saltcedar. The calibrated Penman estimates are thus in excellent agreement with the 1677 mm of seasonal ET estimated above from the Bowen ratio. The results suggest that PET estimates from climatic data could very satisfactorily predict actual ET, once a local calibration was developed from a small set of BREB data.

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ARSENAL AS A CONTROL AGENT FOR SALTCEDAR (TAMARIX)

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ABSTRACT

Arsenal, EPA Reg. No. 241-273, is a broad-spectrum herbicide registered for vegetation control in a multitude of commercial applications ranging from utility rights-of-ways to nonirrigation ditch banks. Arsenal has demonstrated control on over 60 different species of plants including saltcedar (*Tamarix ramosissima*). When used as directed, the herbicide reportedly has no harmful effects on mammals, bees, fish, birds, or earthworms. Arsenal reportedly does not translocate or leach from the soil. It is nonvolatile, nonflammable, and unlike tank mixes, introduces only one biodegradable product into the environment.

INTRODUCTION

There is little doubt that saltcedar (*Tamarix*) was originally introduced as an ornamental during the eighteenth century (Robinson 1965). Some people have speculated that saltcedar was brought in earlier by Spanish explorers (Robinson 1965). By 1933 saltcedar was becoming commonplace along the Green and Colorado Rivers (Christensen 1962). From 1920 to 1970 saltcedar infestations would increase from an estimated 10,000 acres to over 1.3 million acres (Howard, 1983).

Currently, the National Park Service is funding a wide variety of saltcedar control efforts. To date, an acceptable and cost-effective control method to prevent the spread of saltcedar has not been developed. In NPS areas saltcedar is quickly replacing native vegetation and disrupting the historic scene. For example, native species such as cottonwood (*Populus fremontii*), and willow (*Salix* spp.) are being replaced by *Tamarix* (Hasse 1972). However, unlike cottonwood and willow which require constant access to saturated soils, saltcedar can survive for extended

periods of time without access to saturated soils. Consequently, it has be called a facultative phreatophyte (Turner 1974). It has been estimated that a mature saltcedar plant can produce up to 600,000 seeds annually (Graf 1978). Prolific seed production along with the ability of broken branches to take root on moist riparian substrate has given saltcedar a competitive edge and aided in its rapid expansion throughout the West (Sanchez 1975).

PRESENT CONTROL METHODS

Five methods that are commonly used to control undesirable vegetation are prescribed fire, mechanical or manual destruction, killing with herbicides, and biological control.

The use of fire control is generally ineffective. High water and salt content make saltcedar difficult to burn. Consequently, high heat flux is required to overcome these retardant properties. Prescribed fire is difficult to employ and its effects are difficult to predict under extreme burning conditions. Such control is desirable for reduction of impact on the control site. For example, light to moderate prescribed burning retains enough plant litter or duff to protect the soil from high surface temperature and erosion, while severe fires leave the soil bare and alter its structure. The fire must burn with predictable intensity to estimate its control effects accurately. Unfortunately, fire intensities are difficult to predict. In addition, fire may promote species dispersal by extensive root sprouting or other unforseen mechanisms. Saltcedar is also "very fire-tolerant" (Cannon 1988). Peterson (1981) found that burning in conjunction with antitranspirants applications did not increase the control of saltcedar. Often, the manager has to await the proper burning conditions while the fire crew and equipment are held in readiness. Other control methods that are under more direct managerial control may offer greater convenience and certainty.

Mechanical methods usually involve the use of heavy ground equipment with tractor-mounted blades. These methods can be categorized into classes based upon their potential for soil disturbance by erosion, compaction, soil mineral alteration, and nutrient loss. Examples of mechanical methods would include high disturbance techniques such as: mowing, chopping, shearing, scarifying, ripping, piling, raking, and slope disking. Equipment availability, operating costs, site location, and topography limit and reduce the cost-effectiveness of these techniques. Furthermore, it has been reported that when you cut the saltcedar stem off at the base "you get four more sprouts starting off" (Cannon 1988a, 1988b).

Manual methods employ hand tools to cut vegetation above and below ground. Tools include axes, brush hooks, pry bars, clippers, spades, and chainsaws. Manual methods while effective, if carefully done, are time intensive activities best suited for small areas. Generally, manual techniques are not cost effective over large areas.

Biological control methods, if thoroughly researched, are of great value in controlling undesirable plant species over large areas. Unfortunately, a saltcedar biological control program has not been established. Existing USDA research efforts to examine the feasibility of developing a saltcedar biological control program require funding. Several years would be required to develop a saltcedar control program because of the extensive testing and screening required for all biological control agents.

Herbicide effectiveness is dependent upon the choice of herbicide, application method, dosage, host species, environmental conditions, and numerous biological and anthropogenic time factors. These factors should be managed to reduce risks to humans, wildlife, and other environmental elements. Supervision and training of applicators are mandatory to reduce risks associated with accidents and human exposure. However, it should be emphasized that accidental injuries from other methods could pose greater risks to workers than health impacts from herbicides.

ARSENAL AS A CONTROL AGENT

Arsenal is the first compound registered by the EPA from a new class of American Cyanamid chemical agents called imidazolinones (American Cyanamid 1986). Arsenal, after adequate field testing, may offer a cost-effective technique in controlling localized saltcedar infestations. Initial Arsenal control efforts at Attwater Prairie Chicken and Bosque del Apache Wildlife Refuges look promising. According to John Taylor, biologist at Bosque del Apache, "mechanical efforts [i.e., to control saltcedar] only encourage heavier infestation, and most [other] herbicides merely knock the species back temporarily (Cannon 1988a, 1988b).

Arsenal is also recommended for the establishment and maintenance of wildlife openings (Arsenal technical label 1988). Arsenal may be applied with the following equipment: fixed-wing aircraft, helicopter, boom and off-center nozzles, hand-held or backpack spray equipment, and high-volume spray equipment. Arsenal is not registered for direct application to water or wetlands. Whether Arsenal can be applied along dry or intermittent streambeds or wetlands is unknown at this time and requires further clarification from EPA. Additional research is required to examine the potential costs and benefits from an Arsenal-based control program.

ARSENAL FORMULATIONS

Arsenal herbicide is used as an aqueous solution to be mixed in water and applied as a spray for control of most annual and perennial grasses and broadleaf weeds on noncropland areas (Table 1). Arsenal may be applied either as a preemergence or postemergence herbicide; however, postemergence application is the method of choice in most perennial plant situations. To maximize the effectiveness of Arsenal it should be applied at the height of the growing season (American Cyanamid 1986).

Arsenal is absorbed through the foliage and roots and is translocated rapidly to the plants meristematic regions where it accumulates. Soon after effective treatment chlorosis appears in the newest leaves and the sprayed individuals slowly stop growing. For saltcedar American Cyanamid recommends a formulation of 6 pints Arsenal/per 100 gallons water/per acre. Recommended formulations may vary considerably depending upon local environmental conditions and the particular species of interest. Arsenal can diffuse into the soil fabric and persist for numerous months depending on localized conditions. "Once the active ingredient is absorbed into the soil, lateral and vertical movement is limited and because Arsenal is non-volatile it does not move out of the area of application" (Thomas E. Nishimura, American Cyanamid, pers. comm.). Degradation of the active ingredient is accomplished by photolysis and a few aerobic microorganisms. Weather conditions may adversely affect treatments or slow the degradative processes. Technical specifications state that "Arsenal has minimal effect on soil microflora" (American Cyanamid 1986). Unlike many herbicides that tend to break down when mixed, Arsenal, according to American Cyanamid, is stable in field application tanks and during storage.

MODE OF ACTION

Meristematic tissues are those tissues that are actively involved in plant cell division and growth. Meristematic tissues are located in various portions of the plant. For example, those located at the tips of shoots and buds are known as apical meristems. Over time, meristematic cells divide and then elongate causing the plant to grow in length. Growth is possible provided that protein synthesis is not chemically restricted or halted.

According to American Cyanamid (1986): "Arsenal controls vegetation by reducing the levels of three branched-chain aliphatic amino acids, valine, leucine, and isoleucine, by inhibition of acetohydroxyacid synthase," a critical enzyme in the biosynthetic pathway of these amino acids. Without adequate

supply of valine, leucine, and isoleucine protein synthesis is inhibited and plant viability cannot be maintained over an extended period of time. Because photosynthetic pathways are not initially effected, most vegetation may remain green for several weeks before showing signs of chlorosis and or tissue necrosis. Herbaceous species commonly show symptoms of chlorosis within two to four weeks after a typical application. In contrast, susceptible tree species may retain their green foliage for six months after treatment.

Because this biosynthetic pathway does not occur in animals, mammalian toxicity is low. The manufacturer claims that Arsenal "is not stored or accumulated in animal tissues" and that "toxicological studies on Arsenal indicate that laboratory test animals can ingest relatively large doses of the active ingredient without serious effect" (American Cyanamid 1986).

RESEARCH NEEDS

The need for additional Arsenal research is critical. Preliminary research indicates that Arsenal control techniques may be more cost-effective than existing control techniques. Unfortunately, without sufficient data, the effectiveness of any control program cannot be determined.

Research is an integral part of any vegetation control program and is used to acquire knowledge of environmental processes and relationships. Without this knowledge the broader effects of any vegetation management program will not be known. Future research efforts should focus on effectiveness and efficacy of all existing control efforts including techniques involving Arsenal. In addition, if we are to make cost comparisons between different control techniques, standardized monitoring protocols must be developed and control plots effectively established. Without adequate quantitative control methods, management cannot evaluate the cost-effectiveness of any vegetation control program.

Long-term vegetation control programs should be funded on a multiple year basis. Long-term effects on plant and animals, especially threatened, endangered, and sensitive species that are associated with treatment areas, need to be examined in detail. All adverse effects resulting from vegetation control programs should be extensively documented and adequately researched. Good vegetation management is only possible if costs and benefits from control programs are known and clearly delineated.

Table 1. Weeds Controlled

ARSENAL herbicide will provide postemergence control with residual control of the following target vegetation at the dates listed. ARSENAL herbicide should be used only in accordance with the recommendation on this label and the leaflet label.

GRASSES

Apply 2-3 pints per acre*

Annual bluegrass (Poa annua)
Broadleaf signalgrass (Brachiaria platphylla)
Canada bluegrass (Poa compressa)
Downy brome (Bromus tectorum)
Fescue (Festuca spp.)
Foxtail (Setaria spp.)
Italian ryegrass (Lolium multiflorum)
Johnsongrass (Sorghum halepense)
Kentucky bluegrass (Poa pratensis)
Lovegrass (Eragrostis spp.)
Orchardgrass (Dactylis glomerata)
Paragrass (Brachiaria mutica)
Quackgrass (Agropyron repens)
Saltgrass (Distichlis stricta)
Sandbur (Cenchrus spp.)
Smooth brome (Bromus inermis)
Vaseygrass (Paspalum urvillei)
Wild oats (Avena fatua)
Witchgrass (Panicum capillare)

Apply 3-4 pints per acre*

Beardgrass (Andropogon spp.)
Cheat (Bromus secalinus)
Crabgrass (Digitaria spp.)
Fall panicum (Panicum dichotomiflorum)
Goosegrass (Eleusine indica)
Prairie threeawn (Aristida oligantha)
Reed canary grass (Phalaris arundinacea)
Torpedograss (Panicum repens)
Wild barley (Hordeum spp.)

Apply 4-6 pints per acre*

Bahiagrass (Paspalum notatum)
Bermuda grass (Cynodon dactylon)
Big bluestem (Andropogon geradi)
Cattail (Typha spp.)
Dallisgrass (Paspalum dilatatum)
Feathertop (Pennisetum villosum)
Guineagrass (Panicum maximum)
Phragmites (Phragmites australis)
Prairie cordgrass (Spartina pectinata)
Sand dropseed (Sporobolus cryptandrus)
Timothy (Phleum pratense)
Wirestem muhly (Muhlenbergia frondosa)

BROADLEAF WEEDS

Apply 2-3 pints per acre*

Burdock (Arctium spp.)
Camphorweed (Heterotheca subaxillaris)
Carpetweed (Mullugo verticillata)
Carolina geranium (Geranium carolinianum)
Clover (Trifolium spp.)
Common chickweed (Stellaria media)
Common ragweed (Ambrosia artemisiifolia)
Dandelion (Taraxacum officinale)
Dogfennel (Eupatorium capillifolium)
Filaree (Erodium spp.)
Fleabane (Erigeron spp.)
Hoary vervain (Verbena stricta)
Horseweed (Conyza canadensis)
Indian mustard (Brassica juncea)
Kochia (Kochia scoparia)
Lambsquarters (Chenopodium album)
Lespedeza (Lespedeza spp.)
Miners lettuce (Montia perfoliata)
Mullein (Verbascum spp.)

TABLE 1 (CONTINUED)

BROADLEAF WEEDS

Apply 2-3 pints per acre*

Nettleleaf goosefoot (Chenopodium murale)
Oxeye daisy (Chrysanthemum leucanthemum)
Pepperweed (Lepidium spp.)
Plantain (Plantago spp.)
Russian thistle (Salsola kali)
Smartweed (Polygonum spp.)
Sorrell (Rumex spp.)
Sunflower (Helianthus spp.)
Sweet clover (Melilotus spp.)
Tansymustard (Descurainia pinnata)
Western ragweed (Ambrosia psilostachya)
Wild carrot (Daucus carota)
Wild lettuce (Lactuca spp.)
Wild parsnip (Pastinaca sativa)
Wild turnip (Brassica campestris)
Wollyleaf bursage (Ambrosia grayi)
Yellow woodsorrel (Oxalis stricta)

Apply 3-4 pints per acre*

Bull thistle (Circium volgare)
Cocklebur (Xanthium strumarium)
Dock (Rumex spp.)
Goldenrod (Solidago spp.)
Pokeweed (Phytolacca americana)
Purslane (Portulaca spp.)
Saltbush (Atriplex spp.)
Yellow starthistle (Centaurea solstitialis)

Apply 4-6 pints per acre*

Arrowwood (Pluchea sericea)
Canada thistle (Circium arvense)
Giant ragweed (Ambrosia trifida)
Little mallow (Malva parviflora)
Milkweed (Asclepias spp.)
Primrose (Oenothera kunthiana)
Silverleaf nightshade (Solanum elaeagnifolium)
Sowthistle (Sonchus spp.)
Texas thistle (Circium texanum)

VINES AND BRAMBLES

Apply 1 pint per acre

Field Bindweed (Convolvulus arvensis)
Hedge bindweed (Calystegia sequium)

Apply 2-3 pints per acre*

Wild buckwheat (Polygonum convolvulus)

Apply 3-4 pints per acre*

Greenbriar (Smilax spp.)
Redvine (Brunnichia cirrhosa)
Honeysuckle (Lonicera spp.)
Morning glory (Ipomoea spp.)
Poison ivy (Rhus radicans)
Wild rose (Rosa spp.)
Including: Multiflora rosa (Rosa multiflora)
Macartney rose (Rosa bractreata)

TABLE 1 (CONTINUED)

VINES AND BRAMBLES (Continued)

Apply 4-6 pints per acre*

Blackberry (Rubus spp.)**
Dewberry (Rubus spp.)**
Kudzu (Pueraria lobata)
Trumpetcreeper (Campsis radicans)
Virginia Creeper (Parthenocissus quinquefolia)
Wild grape (Vitis spp.)

BRUSH SPECIES

Apply 4-6 pints per acre*

American beech (Fagus grandifolia)
Ash (Fraxinus spp.)
Bald cypress (Taxodium distichum)
Bigleaf maple (Acer macrophylum)
Blackgum (Nyssa sylvatica)
Boxelder (Acer negundo)
Cherry (Prunus spp.)
Chinaberry (Melia azadarach)
Chinese tallow-tree (Sapium sebiferum)
Dogwood (Cornus spp.)
Hawthorn (Crataegus spp.)
Hickory (Carya spp.)
Maple (Acer spp.)
Mulberry (Morus spp.)
Oak (Quercus spp.)
Persimmon (Diospyros virginiana)
Poplar (Populus spp.)
Privet (Ligustrum vulgare)
Red Alder (Alnus rubra)
Red Maple (Acer rubrum)
Saltcedar (Tamarix ramosissima)
Sassafras (Sassafras albidum)
Sourwood (Oxydendrum arboreum)
Sumac (Rhus spp.)
Sweetgum (Liquidambar styraciflua)
Willow (Salix spp.)
Yellow poplar (Liriodendron tulipifera)

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*The higher rates should be used where heavy or well established infestations occur.

**The degree of control is species dependent. Some Rubus species may not be controlled.

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CONTROL OF TAMARISK BY CUT-STUMP HERBICIDE TREATMENTS

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ABSTRACT

Deciduous tamarisk is difficult or impossible to kill by fire, drought, freezing, hypersalinity, prolonged submersion, and repeated cutting at ground level. Consequently, we should not be surprised that the success of cut-stump herbicide treatment depends critically on the technique and dedication of the applicator. Herbicide treatments done improperly or sloppily are almost certain to fail, and may even exacerbate the density of tamarisk growth from a single root system.

INTRODUCTION

A quick reading of this set of instructions is no substitute for experience gained in the field; but it should shorten the period of experimentation that rookie applicators require before becoming humbly respectful of tamarisk's remarkable capability for survival and regeneration.

To summarize, four cardinal rules are presented for tamarisk removal by cut-stump application of systemic herbicide, using Tordon RTU, Tordon 101, Garlon 3A, or Garlon 4:

1. STUMP HEIGHT: Cuts normally should be made within 2 inches of the ground surface.

2. TIMING: Herbicide should be applied to cut stumps within several minutes after cutting.

3. COMPLETENESS: The entire circumference of the cambium layer should be cut and treated.

4. FOLLOW-UP: Resprouting foliage should be cut and treated within a year after the initial treatment.

The following sections will discuss these instructions and related information on tamarisk control.

LAWS AND REGULATIONS

Tordon is a restricted herbicide due to its persistence in the environment after application. Therefore, it is subject to regulation by state departments of agriculture and by county agricultural commissioners.

Government employees and volunteers using Tordon independently must pass an examination to obtain state certification for using restricted pesticides. Garlon is not a restricted herbicide because it decomposes rapidly after application, in a day or less in sunlit water, and something like two weeks to two months in soil. Therefore, it can be used by applicators without state certification and without a permit from the county agricultural agent.

Garlon 4's Use Directions were expanded in June 1987 to include cut-stump applications in California and the Pacific Northwest. Target species for cut-stump treatments are not specified on the label, but are intended to be maple and tanoak in the Pacific Northwest, and tanoak and tamarisk in California, the latter registration obtained partly on behalf of California Parks and Recreation. Dow Chemical now recognizes that the market for tamarisk control covers a geographical area larger than California, and the company is likely to ask EPA for further expanded label coverage to include other western states. In the interim, applicators outside California wishing to use Garlon 4 for cut-stump treatments should obtain Special Local Needs (SLN) registration from their respective states.

HERBICIDE SOURCE AND COST

Tordon and Garlon herbicides are made by Dow Chemical, and can be obtained through Wilbur-Ellis Company. Garlon is more expensive, but has the advantage of being not restricted. Tordon is available in different amounts and formulations, and is cheapest in concentrated form.

HERBICIDE	UNIT AMOUNT	PRICE PER GALLON
TORDON RTU	4 x 1 GAL.	$26.00
TORDON 101R	5 GAL.	$18.70
TORDON 101	5 GAL.	$18.75
GARLON 3A	5 GAL.	$53.80
GARLON 4	5 GAL.	$71.55

Cases of Tordon RTU (Ready-To-Use) include four empty, hand-spray applicator bottles, similar in size and function to a Windex bottle. The 5-gallon containers do not come with applicator bottles. The retail price of Tordon 101 is $37.50 per gallon, but for normal use it is diluted 1:1 with water.

Garlon 3A contains 3 lbs/gallon of the active agent, triclopyr, in the water-soluble amine formulation. Garlon 4 contains 4 lbs/gallon of the oil-soluble ester. The difference in concentration is responsible for the price differential.

Garlon 3A should be applied without dilution on tamarisk stumps. Garlon 4 is sufficiently potent at controlling tamarisk to permit dilution to a 1:2 ratio without loss of effectiveness (Howard et al. 1983). Garlon 4's price per gallon is about $25, after 1:2 dilution with diesel oil.

Garlon 4 contains a surfactant, so it can be mixed with diesel oil or water. Dow Chemical recommends dilution with diesel oil because the diesel permits penetration of bark below the cut surface. The herbicide's efficacy when diluted with water has not been tested.

Tordon RTU carries a blue-green dye so that sprayed areas are easily visible. The other types of herbicide are clear, and the addition of a small bottle of cheap blue ink per gallon of herbicide will greatly aid the recognition of sprayed and unsprayed stumps.

HERBICIDE TOXICITY

HERBICIDE	TOXICITY CATEGORY	HAZARD NOTIFICATION
TORDON RTU	II (moderate)	WARNING
TORDON 101	III (low)	CAUTION
GARLON 3A	I (high)	DANGER
GARLON 4	III (low)	CAUTION

Tordon RTU and 101R contain ethylene glycol, or antifreeze, so that it can be applied in subfreezing temperatures. This ingredient is poisonous, and contact with eyes, skin, and clothing should be avoided.

Tordon 101 does not contain ethylene glycol, so at above-freezing temperatures it has the advantages of being both cheaper and safer.

The active ingredients in Tordon (2,4-D, and picloram) resemble plant hormones chemically, and are not notably toxic to animal life.

Garlon 3A contains methanol as an antifreeze ingredient, which also is poisonous but less so than ethylene glycol. The active agent, triclopyr in the amine form, is slightly to moderately toxic in oral and dermal contact, but "severely injurious" to eyes. Therefore, goggles should be worn during handling, and in California a closed system must, by law, be used for mixing.

Garlon 4 contains petroleum distillates as a carrier. According to Dow Chemical's technical data sheet, Garlon 4 has low oral toxicity, and is nonirritating to skin and eyes, as judged from tests on rabbits.

Injury to neighboring desirable vegetation should be minimal from careful cut-stump applications. Tordon has low toxicity to grasses, and Garlon should not affect neighboring trees. Tordon applications can cause injury to adjacent broad-leaf trees if the root systems are intergrown, but deep-rooted desert trees such as mesquite are resistant to this effect.

HERBICIDE EFFICACY

Tordon RTU and Garlon 3A seem to be equally effective, judging from comparative cut-stump treatments at The Nature Conservancy's Coachella Valley Reserve in California. Tordon RTU has been used successfully at Death Valley National Monument since the mid-1970s; Garlon 3A has been found to be effective at California's Anza-Borrego Desert State Park over the past three years.

Although the cut-stump application method was only recently added to the Garlon 4 label, this formulation appears to be more phytotoxic to tamarisk than Garlon 3A. Comparative tests have determined this at the Ouray National Wildlife Refuge in Utah (Howard et al. 1983) and at California's Red Rock State Park. Dow Chemical representatives have no explanation for Garlon 4's greater efficacy, because for most tree species the water-soluble amine form is the appropriate choice.

TAMARISK TAXONOMY

The invasive species of tamarisk is deciduous and flower-bearing; it normally drops its leaves in winter, and produces numerous small pink flowers in spring. The scaly leaf resembles that of cedar, hence the common name "saltcedar." Several different species names have been proposed by botanists, but *Tamarix ramosissima*, meaning "multi-branched," seems the most descriptive.

A second variety of tamarisk is *Tamarix aphylla*, commonly known as "athel." It is evergreen, with inconspicuous flowers and larger, more solitary trunks. It is not nearly as invasive as deciduous tamarisk, for the seed lacks viability and the tree propagates by the transport and burial of broken limbs during floods.

HYDROLOGIC SETTING

The desert areas most amenable to tamarisk control are: 1) canyons subject to intense flooding and 2) springs that are never flooded.

In the first case, work should start with the larger trees at higher elevations which are likely to survive future floods and reseed the canyon floor; younger trees and saplings, particularly at the lowest elevations, can be ignored as they eventually will be washed away.

Around desert springs that are never flooded, tamarisk removal must be complete to be effective; but once accomplished, the rehabilitation should be permanent, with only minor surveillance needed to remove seedlings derived from distant seed sources.

Tamarisk control will be most difficult, and perhaps impossible, on river courses which flood enough to cause widespread seed propagation, but not intensely enough to uproot established trees.

EQUIPMENT

The essential tools for cutting tamarisk are lopping shears and hand axes. For lopping shears, "Sears Best" is recommended, described as follows by last year's catalog:

> Craftsman compound-action lopping shears. Rust-resistant Teflon-coated steel blades cut branches to 1.5 inches thick. Adjustable anvil, hardwood handles, 29 inches long. Warranted. 71-86128--Shipping weight 3 pounds 8 ounces.....$27.99.

Currently the shears are available at Sears stores but not by catalog order. The quality and mechanical leverage of these compound-action shears give notable improved productivity compared to conventional scissor-type shears, and are well worth the extra expense.

For larger trees, a chain saw will be optional or required, depending on the accessibility of the main limbs. Thick, solitary trunks are more easily treated by girdling with a hand

ax, rather than by felling the tree and spraying the stump, because with girdling, the tall heavy limbs do not require removal.

More commonly, however, deciduous tamarisk is multi-trunked, and partial or complete cutting is needed to gain access to the entire bark surface at ground level.

The applicator spray bottles delivered with Tordon RTU usually function well, but some leak or drip herbicide from the nozzle or the trigger. Inexpensive replacement heads which screw onto the labelled applicator bottles can sometimes be found at supermarkets.

An applicator following several chainsaws in a dense stand of tamarisk will find it convenient to use a larger dispenser, with a hand pump for pressurization and a short hose to the nozzle, obtainable at garden supply stores.

SEASON OF YEAR

The instructions for Tordon and Garlon indicate that applications can be made in any season "except during periods of heavy sap flow of certain species such as maples or during drouthy (drought) periods."

Tordon applications on deciduous tamarisk work best during fall and winter, when the tree is dormant or going dormant. Spring does indeed appear to be the least favorable season, when sap flow is strongly upward from the root system. Although spring months can provide the most comfortable working conditions in desert areas, herbicide applications at that time must be especially thorough and close to the root crown to be successful.

Despite the lower success rate of spring applications, the late spring months--from April to June--are the only practical time to search for tamarisk seedlings mixed with other vegetation, because only then can small plants be easily distinguished at a distance by their pink flowers.

HERBICIDE APPLICATION METHOD

The Use Directions for Tordon recommend cutting the bark and cambium layer "as close to the ground as feasible." As a general rule for treatment of tamarisk, the spacing between cut and ground level should be 2 inches or less. Higher cuts of 6-12 inches above ground are reportedly effective for applications of Garlon 4 during autumn months (Howard et al. 1983).

The bark wound can be made by either girdling with an ax or cutting the limb completely with lopping shears or chainsaw. For larger trunks, girdling is the most effective treatment, because the shallow downward cuts tend to trap and pond the herbicide, allowing prolonged seepage into the vascular system.

Often, chainsaw cuts must be made higher than 2 inches from the ground to prevent the saw blade from striking rocks and soil. In such cases, the tamarisk stump should be girdled with an ax after cutting, before the herbicide is applied.

The Tordon Use Directions are silent on the point, but the cut stem or trunk should be sprayed within minutes after making the cut. Waiting several hours before applying herbicide allows the tree time to start closing off the wound, lowering the mortality rate drastically.

The entire circumference of a tree must be cut and treated, because herbicides absorbed by the vascular system do not appear to move circumferentially in the root crown.

HERBICIDE CONSUMPTION

A single gallon of herbicide should be sufficient to treat hundreds of trees or thousands of seedlings. Only a light spray is required on the cambium layer next to the bark; the interior portion of thick trunks, cut off at ground level, can be left dry.

As a general guideline, a group of 10-15 workers can be expected to use about 1 gallon per day, if they work efficiently with appropriate tools and do not apply herbicide too heavily.

MORTALITY RATE

Under favorable conditions the mortality rate of tamarisk after Tordon treatment should exceed 95%. Less successful applications are usually attributable to not cutting the bark circumference completely or low enough to ground level.

Some amount of resprouting is inevitable. A follow-up visit to treat resprouting stumps is always necessary several months to a year after an initial treatment. In some cases during the spring months, a treated stump will produce stems several inches tall before dying. For this reason, follow-up inspections should occur after 3-4 months have passed, so that there is no uncertainty over which stumps are dead and which are alive.

Tamarisk trees on floodplains can be more difficult to kill, requiring several treatments. The root systems are more extensively developed near the ground surface, due to repeated scouring and removal of limbs by floods, and can send up shoots where none existed at the time of initial treatment.

When surveying resprout densities, the applicator should remember that without herbicides, each cut stump would send up perhaps 10 to 30 shoots. If a treated stump produces only one or several resprouts, then the herbicide has performed quite well by killing most of the root system. Cutting and spraying resprouts from a small percentage of stumps is easy work, compared to the initial treatment. If financial resources exceed labor resources, resprouting foliage can be sprayed with Garlon herbicide without cutting.

Although proper application technique is important, it is necessary to find a balance between working with thoroughness and working with speed. When confronting shallow lateral roots or partly exposed root systems, for example, it is more efficient to work quickly on the first pass; then, after seeing what survives, one spends more time on follow-up visits to dig out and treat the more inaccessible roots.

DISPOSAL OF CUTTINGS

Tamarisk cuttings can be voluminous. To permit access to stumps after cutting and avoid smothering the native shrubs and grasses, cuttings should be stacked nearby on dry bare ground or dead vegetation. Other than for aesthetic considerations, there is no reason to remove cuttings any significant distance from the work area. If not destroyed by flooding or fire, the cuttings will eventually decay in place.

Tamarisk seeds remaining on cuttings are not a cause for concern, because the seeds lose viability after a few weeks of summer heat.

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THE STATUS OF ECOLOGICAL RESEARCH ON TAMARISK (TAMARICACEAE: TAMARIX RAMOSISSIMA) IN ARIZONA

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ABSTRACT

Surprisingly little information is available on the ecology of tamarisk. Ecological experiments and measurements on this species's life history characteristics and interactions with other common riparian species are underway at Lees Ferry, Arizona, and in the laboratory at Northern Arizona University. The progress of this experimental program and a brief discussion of tamarisk reproductive strategy are presented.

INTRODUCTION

Despite the wealth of information published on tamarisk, or saltcedar, (*Tamarix ramosissima*), there has been virtually no attempt to compile life history or ecological information on this widespread exotic phreatophyte. It has been claimed that tamarisk is an aggressive competitor in riparian settings, an anemophilous and self-pollinating species capable of continuous seed production throughout the growing season, and capable of vigorous vegetative reproduction (Brotherson and Von Winkel 1986); however, fundamental assertions concerning its pollination strategy, out-crossing requirements, and its genetic variability remain untested. Although tamarisk has undesirable effects in many water courses, it is apparent that this species may be an ecologically neutral or even beneficial addition to some riparian ecosystems (e.g., Brown et al. 1984).

Here I summarize ecological information and experiments underway at Lees Ferry, Arizona, and in the Grand Canyon, conducted under the auspices of the National Park Service. This research is designed to elucidate life history characteristics at several stages (seed, germination, seedling, and mature plant stages), and to evaluate the effects of ecological factors (environmental gradients, disturbance, competitive interactions, and herbivory) on tamarisk growth and reproduction. While the information reported here relates specifically to the tamarisk population in northern Arizona, most of the conclusions are believed to apply elsewhere in the range of tamarisk. This investigation into tamarisk life history strategies and ecology was stimulated by

evidence of recent successional replacement of tamarisk by native species along the Colorado River in Grand Canyon National Park. Ecological stability of the riparian corridor, conferred by impoundment of the Colorado River upstream from the Grand Canyon, is believed to be responsible for the replacement pattern observed there.

METHODS

Field and laboratory experiments and measurements were designed to elucidate aspects of tamarisk life history traits, and this species' responses to environmental gradients (light, moisture, and nutrient availability), disturbance (flooding and desiccation), predation (herbivory), and competition at several stages in the life of the plant. Field studies have been conducted at Lees Ferry, Arizona, and in the Grand Canyon, and laboratory work has been conducted at Northern Arizona University in Flagstaff, Arizona. Observations on tamarisk flowering phenology and seed production have been made on more than 30 mature plants and monitored at 5-week intervals since 1985 at Lees Ferry. Invertebrate pollinators were excluded from 10 flowering branches to assess entomophily as a pollination strategy. Responses to environmental gradients (light, moisture, and nutrient availability) are being assessed at the seedling level with nutrient addition experiments in the laboratory, and among older age classes at Lees Ferry. Numerous other minor experiments and measurements are planned to assess germination requirements and growth responses under various environmental conditions. Disturbance (flooding and desiccation) effects on tamarisk survivorship and growth were studied in the field by Stevens and Waring (1985) and experimentally by Waring and Stevens (in press). Impacts of herbivores were assessed by exclusion experiments and by mechanical defoliation of 0%, 25%, 50%, 75%, and 100% of the leaf area of six replicates of 2-to-4-year-old plants at three sites. Information on the invertebrate and vertebrate herbivores associated with tamarisk in the United States has been compiled (Stevens 1976a,1976b; Stevens unpublished 1985).

Competitive interactions between tamarisk and coyote willow (*Salix exigua*), as well as other common riparian plant species, is under investigation at three life history stages, including seed, seedling, and mature plant stages in the following experiments: 1) experimental assessment of allelochemical inhibition of germination of and by tamarisk; 2) seedlings of tamarisk and coyote willow (*Salix exigua*) have been sown together or separately in pots to investigate interspecific competitive interactions at the seedling stage; and 3) competition between older age-class plants is being assessed through 10 replicates of a replacement and density series effects experiment with 1 to 6 plants/3-gallon pot.

RESULTS

The Seed Stage: Tamarisk produces phenomenal quantities of seeds which are minute (mean dry mass=0.014 mg/seed, n=100) and readily wind dispersed (mean fall rate in still air=0.187m/sec, n=100). Tamarisk seeds produced during the summer remain viable for up to 45 days under ideal field conditions (ambient humidity and full shade) or as little as 24 days when exposed to direct insolation and desiccation. Winter field longevity under ideal conditions is approximately 130 days. Seed mortality appears to be due to desiccation.

The Germination Process: Tamarisk seeds germinate equally well in light or dark, and have no dormancy or after-ripening requirements. Germination requires direct contact with water or extremely high humidity, and is extremely rapid. At 20 degrees C. imbibition lasts for approximately 2 hours, during which time the seed swells to about twice its normal size. The hypocotyl may begin to emerge at 2 hours, and the seed becomes photosynthetic within 5 to 10 hours. Germination "root hairs" emerge by hour 10 and the seed coat (with the pappus still attached) is shed between hours 10 and 20. Tap root emergence begins after hour 20. Thus tamarisk germination is usually completed in less than one day.

The Seedling Stage: Seedling tamarisk are found in a wide variety of situations, from fine sediments to cracks in bedrock, from below sea level to more than 2000m elevation, and in salinities exceeding 50,000ppm; however, the greatest densities are found in fine fluvial substrates as floodwaters recede. Results of controlled growth rate experiments demonstrate that tamarisk seedlings grow considerably slower than most other common riparian plant species: total biomass accumulation rate=0.25mg/day, and stem elongation rate=2-5mm/day during the first month of growth (Waring and Stevens in press). Nutrient and water addition experiments demonstrated that water availability regulated the biomass accumulation rate, while nutrient availability to regulated root: shoot allocation patterns. Even as seedlings, tamarisk were more desiccation tolerant than were coyote willow seedlings. Tamarisk seedlings may flower in their first year of growth (Warren and Turner 1975) but most begin to reproduce in their third year or later.

Mature Plant Characteristics:
Growth: Mature plants grew apically and also produced numerous lateral shoots, most of which died presumably from inadequate light. Those few lateral shoots that survived grew more than 1.0m/year. During 15 years of observation, most plants in northern Arizona produced two flushes of foliage, one in April, May, and the other in late July. Premature chlorosis was repeatedly noted in tamarisk in mid-to-late August, more than 2 months before the growing season usually ended.

Reproduction: Tamarisk was found to produce phenomenal quantities of pink, red, or white flowers, each capable of producing 8 to more than 20 seeds. At low elevations in northern Arizona, flowering commenced in late April about 1 month after bud-break and peaked from mid-May to early June. Plants which were not water stressed continued to bloom at low to moderate levels throughout the growing season, while water-stressed individuals ceased reproduction following the spring blooming period. Reproductive effort was inexplicably variable in tamarisk, with approximately 5% of the plants failing to flower in 4 years of observation.

Pollination: Experiments in which tamarisk racemes were bagged to prevent insect pollinator from reaching the flowers demonstrated conclusively that virtually no seed development occurred without insect visitation. Wind pollination and selfing are still under investigation; however, preliminary tests show that neither anemophily nor self-compatibility appear to be likely reproductive strategies for tamarisk.

Ecological Factors That Regulate Tamarisk Populations: Environmental Gradients: As mentioned, nutrient addition experiments produced strong responses among tamarisk seedlings, with nitrogen and then phosphorus having the greatest effect on growth. Experiments are currently underway using field plants in pots to determine the relative significance of water stress, nutrient stress, and light limitations on older age classes. Preliminary results and field observations indicate that older tamarisk are tolerant of water and nutrient stresses, but are highly susceptible to shading, with shaded plants having greatly altered leaf morphology and reduced reproductive effort.

Disturbance: A deep taproot (Gary 1963), rapid production of adventitious roots, and the ability to survive inundation for as long as 3 years in cold, well-oxygenated water (Waring and Stevens in press) allow tamarisk to survive prolonged flooding events, such as occur in regulated streams (Stevens and Waring 1985). Measurements of plant water potentials at Lees Ferry reached below -30 bars, and demonstrated that tamarisk is also capable of surviving high levels of desiccation stress. Accidental and control-oriented fire is becoming more frequent in tamarisk stands. At one tamarisk burn at Lees Ferry, 90% of the mature plants survived a hot, canopy fire and resprouting shoots exceeded 2m in height within 5 months. The phenomenon of stress induced flowering was observed in August at this burn site: 69.4% of 144 burned plants were blooming heavily, while only 10.9% of 101 unburned plants on adjacent control areas were blooming ($p < 0.001$, $df=2$).

Herbivory: More than 200 species of invertebrate herbivores have been recorded from tamarisk in the United States; however, only 6 are sufficiently common in northern Arizona to qualify as pests

of this plant species (Stevens unpublished 1985). In order of significance these insects include: *Opsius stactogalus* (Cicadellidae), *Chionaspis etrusca* (Diaspididae), both exotic; two species of mirid plant bugs near *Parthenicus* (Miridae); *Schistocerca shoshoni* (Acrididae); and an unidentified flowerfeeding moth. *Frankliniella occidentalis* (Thripidae) occurs in astounding abundance on tamarisk flowers during the summer months, but its impact on tamarisk has not been assessed. All other invertebrate herbivores are incidental on tamarisk foliage in northern Arizona. Significant vertebrate herbivores on tamarisk include beaver and sapsuckers (*Sphyrapicus varius*); while rodents and/or lagomorphs may rarely consume young foliage. Spraying of 50 stems with Malathion to prevent insect herbivory failed to increase the growth of treated tamarisk branches over controls sprayed with water (Stevens 1985 unpublished). Mechanical defoliation of 0%, 25%, 50%, 75%, and 100% of the foliage (6 replicates/treatment, experiment repeated three times) demonstrated that herbivory must exceed 75% before reduction of apical growth rate occurred.

Competition: Tamarisk germination was not reduced in a strong solution of soil leachates from tamarisk or coyote willow. Self-thinning occurs rapidly among young tamarisk, with densities of more than 8,000 seedlings/m2 immediately following germination, to several hundred plants/m2 by the third year, to several plants/m2 by year 15, to less than one plant/m2 by year 30. Thirty seedling coyote willow grown with 30 seedling tamarisk reduced the growth of tamarisk seedlings by more than 80% over controls. A replacement and density series experiment in progress shows strong density effects but no clearly discernable interspecific competition effects.

DISCUSSION

Much more work is planned and/or underway in this project; however, several trends are apparent from the data compiled here. Tamarisk is an extremely fecund, relatively long-lived phreatophyte which is remarkably tolerant of inundation, desiccation, and nutrient stress. Recently flood-disturbed habitat with little or no overstory is required for successful establishment. Despite its fecundity, season-long seed production, stress tolerance abilities, and the abundance of suitable germination habitat, particularly along regulated waterways in the American West, tamarisk does not appear to be a strong competitor under field conditions, and seems particularly sensitive to shading.

Control measures taken against tamarisk should be based on a thorough understanding of the ecological role this species plays, and its contributions as well as its detrimental effects on riparian ecosystems. In particular, substantial habitat reclamation efforts should be considered following tamarisk control to

prevent immediate recolonization by tamarisk and to restore valuable riparian habitat (Johnson et al. 1985).

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Summary Report of NPS Tamarisk Workshop

COMMITTEE REPORTS: TAMARISK RESEARCH AND MANAGEMENT

Peter S. Bennett and William J. Burke, Chairs

ABSTRACT

Workshop participants view the 1987 tamarisk situation with concern. These nonnative plants are becoming established in native ecosystems while basic facts about the genus are either lacking, contradictory, or in a state of flux. Even the taxonomic situation with *Tamarix* is fluid and species are difficult to identify with certainty. Tamarisk literature is widely scattered and insufficiently compiled. The distribution of various species in the United States is poorly known, its effects on native ecosystems and ecological processes are in need of further study, and fully effective means of control have yet to be demonstrated.

WORKSHOP DISCUSSION

National Policy

Historically there has been no national policy directing all federal, state, and local governments to direct efforts toward control, cooperation, etc. with regards to the management of tamarisk. Policy for its management was usually on a regional level within individual agencies. Since the tamarisk problem is primarily in the Southwest, much of the nation does not identify tamarisk as a problem species. Likewise, tamarisk has not even been listed as a noxious weed or undesirable plant on a national level. Because so many water management agencies must manage this plant to conserve water resources and keep waterways open, we would recommend that a statement (on a national level) be developed that binds agencies toward accomplishing a joint effort on funding and control actions that will most efficiently manage tamarisk and bring the highest benefit from those actions.

Interagency Liaison

The first efforts at an interagency group for tamarisk control developed in the 1960s when a number of agencies having problems with tamarisk related to water management formed a subcommittee which met annually to discuss phreatophytes on river systems and the need for research. This subcommittee disbanded in the early 1970s. For the past 15 or more years agencies have dealt with

tamarisk control within their own organizations to correct their own unique problems with this plant.

The unique missions of different agencies have probably kept potential cooperating agencies from seeing that they have a common problem. However, the diverse number of agencies that have tamarisk problems, and that are working on solutions to those problems, has recently come to light as more literature on tamarisk becomes available and more contacts are made between agency personnel.

Recognizing now that many agencies have a common problem with tamarisk, it is recommended that an interagency taskforce be formed to evaluate tamarisk research and put coordinated effort into finding the most efficient and environmentally safe method of controlling tamarisk. A cooperative effort among agencies will reduce the amount of duplication of research and make the most efficient use of funds available for tamarisk control. It will also keep agencies aware of programs and objectives that each other have identified to fulfill their missions. Federal, state, and local governments with tamarisk problems should be invited to join this cooperative effort. This group would also act as a clearinghouse for information that can be used on individual park programs, procedures, funding availability, research results, etc. One of the Cooperative Park Study Units (CPSU) in the Southwest would be a most logical representative for the National Park Service on an interagency taskforce for tamarisk management.

PROBLEMS

Workshop participants specifically identified knowledge in the following subject areas as inadequate:

1. There is no comprehensive annotated bibliography available and no system in place to prepare and maintain one.

2. Research on the genus is inadequate. A scan of the current electronic data bases indicates that only 35 articles have been published in the last 20 years, worldwide. Data on reproductive success, seed viability, dissemination and dispersal, phytotoxicity, and ecological amplitude are lacking.

3. The range and distribution of alien tamarisks is unknown. It is unknown if the genus is still expanding in the United States.

4. Effective and efficient control measures have not been developed for tamarisk. This is particularly true for biological control.

5. At the present time there is no agreement or uniformity among tamarisk control workers about how to record data or what measurements to make. Some persons report results based on stems per acre, some on absolute cover, some on relative cover, some on the basis percent resprouts, etc., etc. Some persons record weather conditions, soil conditions, treatment methodology, application rates, etc., but many do not. This situation is so chaotic that it is often impossible to compare the results obtained by different treatments. Thus each manager has to "reinvent the wheel."

These problems are too big to be handled on a casual basis by any single land managing agency. During these financially difficult times no agency seems willing to undertake a leadership role in organizing an attack on tamarisk and there does not seem to be a national will to mount a large-scale attack.

RECOMMENDATIONS

The Tamarisk Ecology and Research Committee recommends that the Tamarisk Task-Force remain in existence as an interagency committee to continue the work of data sharing, research proposal review, research and monitoring design, and preparation, coordination, review of action plans, and above all communication. Managers working in isolation know that they have severe tamarisk problems but do not understand their full magnitude or strategies for dealing with them. Therefore a combined resolve for dealing with the problem on a national scale is lacking. Continuation of the task force on an interagency basis is necessary. Workshops should be held every two years. This is our highest priority recommendation.

The Tamarisk Task Force should appoint a small committee to draft protocols for recording monitoring and treatment data. Adoption of these protocols will put an end to the present chaos and ensure that information gathered can be transferred from project to project and from area to area.

Literature available should be organized, placed in an annotated searchable bibliography, and synthesized. When possible, copies of papers dealing with tamarisk or tamarisk-related topics should be obtained. All topics involving tamarisk are to be included. The first tamarisk workshop resolved that a bibliography should be compiled but lacking funds, the project has languished. Approximately $7,000 is needed to do the work and publish the results for task force members. The CPSU/UA would be willing to oversee the work and will seek funds through the NPS Western Regional Office.

The Tamarisk Ecology and Research Committee recommends that the following research be undertaken:

1. Determine present distribution of tamarisk in the United States. At the present time the invasive distribution of *Tamarix* spp. in the United States is unknown but is believed to be spreading vigorously. A basic inventory of tamarisk distribution is essential before plans for control or eradication can be made and estimates of cost prepared. This data can only be gathered by a large U2 remote sensing inventory. Useful photography already exists and the tools for interpreting the data have been developed. The committee recommends that this research should be designed, coordinated, and funded through the Interagency Tamarisk Task Force.

2. Compile information on tamarisk ecology. Research is needed to determine:

   a. What native plant density is required to stop tamarisk invasion.

   b. Plant associations that have been invaded by tamarisk.

   c. How to reestablish climax vegetation on disclimax sites following tamarisk removal.

   d. Autecology of the species common in the United States, especially reproductive success, seed viability, phenology, and ecological amplitude.

   e. Synecology of communities commonly invaded by tamarisk; especially consider edaphic factors and relationships with mammals and birds.

3. Compile information on tamarisk control. Research is needed to:

   a. Determine effectiveness of herbicides under different conditions for killing tamarisk and the degree to which untargetted species survive.

   b. Develop standardized herbicide testing protocols considering conditions of application, time of year, herbicide type, effects on nontarget species, and methods of application.

   c. Provide for uniform testing of new herbicides and comparison with existing compounds.

d. Compare the effectiveness of mechanical treatment in contrast to or in combination with chemical treatment.

e. Sponsor, design, and implement research directed to achieve biological control of invasive tamarisk species.

FUNDING

Historically, funding for tamarisk management has come on a piecemeal basis with each park identifying its problem and requesting funding to accomplish a project. This often results in duplication of research since other parks or other agencies may be carrying similar experiments or research on tamarisk control. Often the funding would come toward the end of a fiscal year which may be an inopportune period of the year to actually accomplish tamarisk projects with best results.

Since most tamarisk control problems are currently found in the Southwest, a combined effort should be made by Western and Southwest regions to identify tamarisk research monies that can go into a coordinated research effort to find the most effective and environmentally sound control methods. These monies may be combined with tamarisk funding from other agencies to accomplish high level interagency research projects. An effort would have to be made by the interagency task force to identify available monies for tamarisk control projects. This would not only include federal and state agency funds, but also funds identified for tamarisk control in municipal governments and the private sector. Individual parks with the need to control tamarisk would continue to request funds through project statements in their resource management plans. For most efficient use of money on a control project, the park would contact the CPSU on the interagency task force to get the latest recommended control methods for their particular situation.

Finally, requests for funding cyclic maintenance control of tamarisk should be included in any long-term tamarisk control project. These monies will be used to keep tamarisk controlled at locations that cannot afford to have reinvasion occur. Cyclic maintenance money should be guaranteed so planning can be accomplished and the work carried out during the most effective times of the year.

An effort should also be made by the regional offices to find a way to allot money over the life of a project (2, 3, 5 year, etc.) rather than on a year-to-year basis. It would also make more efficient use of funds if money could be carried over to the next fiscal year since sometimes money becomes available late in the year but no work can be done due to the inappropriate season. (If money becomes available in June, it will do no good if the

project has to be accomplished in October or November.) Lead time in knowing that funds are available for tamarisk projects and being able to utilize those funds in a timely manner (not rushing a project or doing it halfway because the money must be spent before a certain time) is most important to initiating a project and having it completed in the most efficient and effective manner.

FUTURE MEETINGS OF THE TAMARISK TASK FORCE

Workshop participants strongly recommend that the National Park Service:

1. Continue to support tamarisk task force meetings, and research and management meetings on a regular, annual, or biennial basis,

2. Seek financial and functional cooperative support from other agencies and expand interagency task force participation including developing interagency agreements, and

3. Actively solicit and compile critical interregional and interpark needs and obtain support for those needs.

Appendix

TAMARIX CONTROL

Gerry Hoddenbach
Southwest Regional Office

SPECIES

Saltcedar: Family Tamaricaceae; *Tamarix* spp.; saltcedar, pinabete

DESCRIPTION

About 54 species native to North Africa/Mediterranean to Pakistan; 7-8 U.S. and Canadian species introduced as ornamentals/streambank and wind erosion control from Asia in early 1800s. *T. aphylla* (athel tree) rarely a problem species; a large-sized evergreen used as an ornamental for shade/windbreak, flowers (but seeds are sterile), propagates by transport/burial of broken limbs during floods. Deciduous tamarisk naturalized, small tree/shrub; rapid colonizer/vigorous invader of disturbed southwestern habitats. *Tamarix* escaped cultivation (from wind/water transport of pollen-size/light-weight seed (1 tree yield 1/2-million seeds/season) and colonized riparian vegetation zones.

DAMAGES/PROBLEMS

Tamarix ramosissima (Saltcedar):

* grows up to 1-foot per month (most growth in early spring, leveling off sharply by midsummer) and crowds/shades out native species; replaces cottonwood and willow.

* is more resistant to drought than native species (out-competes them);

* not only tolerates excessive salinity in water/soil (652 to 15,032 ppm) but also excretes salt from openings in scale-like leaves (salt falls to ground and kills emerging grasses/seedlings of other species) and even tolerates pollution from European cement factories;

* is not killed by fire/cutting at ground level/application of foliage herbicide (root system must be killed to prevent resprouting);

* blocks drainages causing increased sedimentation and flooding potentials. In optimum conditions, desert riparian areas may

be converted to an impenetrable Tamarix thicket in less than a decade.

* evapotranspires enormous quantities of water from ditches, springs, etc. Lloyd Gay, Univ. of AZ is working on evapotranspiration and U.S.D.A., A.R.S in Temple, Texas has evapotranspiration data.

* alters wildlife habitat: 4 bird species/100 acres are reported from *Tamarix* habitat (although extensively used by white wing dove, Bell's vireo, mourning doves) while 154/100 acres are known from mesquite habitats. *Tamarix* seeds have no protein content and the plants create a poor understory condition; mesquite seeds have a high protein content and plants provide bighorn forage and rodent community habitat. Although bank beaver will eat young shoots of *Tamarix*, they choose cottonwood over *Tamarix* by about 9 to 1; thereby, continually moving a habitat to Tamarix dominance.

PLANT CHARACTERISTICS

Tamarix grows in <u>any</u> substrate (even found on salt domes) as seedlings from below sea level to +7,000 feet mean sea level. Its roots may penetrate soil 30-feet or more but the plant cannot survive if moisture is suddenly removed from root zone; water table depth must be less than 20 feet. Tolerates inundation (which also removes competing plants) for up to 3-months; when flooding subsides moist soil provides for *Tamarix* seed germination/vegetative rooting. Moist climate of eastern Kansas considered too wet for *Tamarix*. Slat flats located several hundred feet away from channels provide favorable habitat for *Tamarix* but not other species. 100% volume density *Tamarix* stands reported to transpire 7.2-acre-feet water, depending on water table depth/stages of growth.

Seeds: A mature plant may produce 5-10 seeds from each flower or about 1-1/2 kg of seeds; seeds are wind dispersed; dispersal accounts for about 15 km/year wind-migration of plants. Seeds lose much viability within several months of normal temperature: Larry Stevens (="Stevens", from Northern Arizona University) found 40-45 days longevity of seed during optimum summer weather; 24 days in sunlight; and 130 days during fall of year.

Germination: Stevens: If seeds are not germinated during 1st summer, almost none germinate following spring. Seeds require no dormancy/light requirements but only germinate on moist soil. Sees germinate after soaking for 2 hours in water then: 5-10 hours to begin photosynthesis, 10-15 hours for hypocotyle formation, 20+ hours for seed coat to be shed, and 20-30 hours for tap root to form. Although this seems fast, root elongation

in *Tamarix* is actually slower than in other riparian species such as acacia, mesquite, cottonwood, and some willows which show faster root elongation and good potentials for out-competing Tamarix. Seedlings of Tamarix are very resistant to desiccation and adaptable to micro-site conditions; this helps them out-compete the other riparian species.

In other tests, 57.1% of seeds germinate in 24-hours on moist medium, 24/2% more during 2nd 24-hours, and 98% germinate in 5-days; germination reported to range from 40-45% during first 2 months, 20% or less from 4th-8th month and then decreases rapidly. Allelochemical inhibition occurs: 75% reduction in Tamarix germination when under coyote willow or when treated with macerated coyote willow parts.

Growth: Plants germinating in July averaged 3-ft. tall in a year (1-2-inches growth/day is average in good sunlight) and had 10 basal shoots/plant (90% die); growth of 12-feet/year reported; flowers/seeds often produced in 1st growing season but more often not until plant is 3-4 years old; roots/stems detached from the plant develop adventitious roots on moist soil. Flower in northern Arizona in late April-May to October. Red or white flowers are constant to specific plants; 5% of the plants do not reproduce. Strong blooming plants remain so year after year. Pollination is insect controlled, not wind borne; plants do not self-pollinate and genetic variability in any population is very high (=plants are genetically very variable). Tamarix usually drops its leaves in winter. Plant may live 50-100 years under natural conditions.

Natural Regulation: Water regulates biomass accumulation (i.e. growth), nutrients regulate how biomass is apportioned to roots/shoots (low nutrients create increased root development). Potassium chloride may be allelopathic when it builds up under plants. *Tamarix* requires light to grow, willows seem to do well with relatively less light than *Tamarix*. Shading inhibits Tamarix flowering. Flooding/scouring often kills 50% or more of plants but drowning is not always effective; Tamarix is much more resistant to drowning (up to 100 days inundation in cold water) than other riparian species. Up to 90% recovery is rapid following fire. Any high stress (fire, drought, chemicals, cutting, etc.) greatly increase flowering and seed production as well as plant distribution (use systemic herbicides before flowers mature). Artificial defoliation required 75% foliage removal to slow growth down. Herbivory is not important to *Tamarix*. Beaver cuttings because 50% or more of shoot that root may increase *Tamarix* stands. *Tamarix* self thins to only a few plants per meter-square after 10-30 years. Willow greatly reduces growth of *Tamarix*.

HISTORY

* Cultivated along Little Colorado drainage near Winslow by 1909; wild Tamarix first noticed on upper Gila River in Arizona after a flood in 1916, common by 1920s, abundant in 1930s, dominant riparian tree replacing cottonwood/willow in 1940s; known growing wild along the Little Colorado in 1937.

* In 1920, Tamarix noted as colonizing major riverways but still occupied less than 20,000 ha.; rapid spread during 1925-1960 (invaded/brought in to Canyonlands in Utah in 1925-1931) with the greatest rate of spread from 1935-1950 to an estimated 900,000-acres. In 1950, *Tamarix* invasion came to attention of Arizona/New Mexico water-supply/flood-control authorities. In 1961, estimated 1400 square mile flood-plain land covered in western U.S. Rapid spread also seen in central Utah and New Mexico/Texas Rio Grande/Pecos River valleys.

* *Tamarix* now occupies well over 500,000 ha. in 15 of 17 western states, major infestations in Texas, California, Nevada, Arizona, New Mexico, Colorado, Utah, Oklahoma; most widely distributed/important phreatophyte in region. Partly, *Tamarix* invasion followed widespread destruction of natural plant communities of northern Arizona from overgrazing, drought, flooding.

ESTABLISHMENT

Establishment favors changing physical/hydrologic factors and disruption of native riparian communities. Air-transported seeds produce rapidly maturing seedlings (may flower in 1-year), easily colonize stream sides/replace native vegetation; resultant jungle-like stream bed growth contributes to stream sedimentation/flooding.

Tamarix primarily draws moisture from saturated soil in vicinity of water table; reported to dry-up springs critical for wildlife use (major area of concern). It may survive indefinitely in absence of saturated soil; a facultative phreatophyte (surviving drought for extended periods of time vs. obligate phreatophytes such as cottonwood/willow requiring uninterrupted access to saturated soil). *Tamarix* stands thought to use large quantities of water, up to 1.2 X 10-9th cubic meters annually consumed in Southwest each year; or, 1-large tree uses 200-gallons/day. Dominant *Tamarix* stands may "dry up" wetlands. Although *Tamarix* displaces native vegetation and is poor source of food/shelter for desert wildlife, it may be important for white-winged dove.

DOCUMENTARY

At Death Valley's Eagle Borax Spring, Tamarix proliferated in mid 1950s from over-grazing by horses; by late 1960s marsh surface water had disappeared, native grasses/reeds were replaced by *Tamarix*. After burning *Tamarix* in 1972, persistent removal by cutting and systemic-herbicide stump application continued for 10-years. By 1982, *Tamarix* gone and marsh recovery rapid/impressive: surface water/migratory birds returned, grasses/reeds flourished. Pete Sanchez worked on this project.

CONTROLS

Flooding for 24-months or for 2-3 successive growing seasons gives good (99%) control (Bear River Bird Refuge, Utah).

Mechanical removal only about 54% effective. Carbohydrate reserves influence root suckering/stump sprouting/internodal expansion are lowest in Nw Mexico/Arizona plants in early summer (May-June), greatest in late fall-winter. Mechanical cutting, to be effective, should be done May through July.

Burning every other year reduced *Tamarix* competitive ability (Ouray National Wildlife Refuge, Vernal, Utah). Burning then chemically treating regrowth did not increase control of plants. Very hot burns may kill the plant.

July fires at Ouray Refuge prevented resprouting by 64% in year following burn; Sept. and Oct. fire prevented resprouting by 9% and 4%, respectively. Spraying following July fire prevented 99% of resprouting; spraying following Sept. and Oct. burns prevented resprouting by 12% and 5%, respectively. Differences in fire response due partly to morphological/physiological conditions of plants, in part to different degrees of heat from each fire. Higher heat yield in July from lower wind speed, lower moisture content of fuel. Spraying following July burn effective because plants were defoliated, root crown buds sprouted, and 2,4-D readily translocated to roots.

Previous poor burn responses show failure because plants dormant when burned, had potential to recover by resprouting from basal stem buds, most fires too cool to do seriously damage basal stem buds.

Hurst (1981) did not find single-time burning provided substantial control, multiple burns were effective control.

Electrical arc: about same effects as burning.

Combinations: one author stated root-plowing, raking, burning acceptable mechanical control measures for most phreatophytes but *Tamarix* normally needs repeated treatments for successful control and management must continue control programs. Others state effective removal requires: (1) mechanical uprooting, (2) cutting at ground level, (3) stump application of systemic-herbicide = combinations of cutting/herbicide application. Cut stump application, although costly, is very controlled, doesn't effect non-target organisms, causes least environmental impact. Foliar applications less expensive but degree of control much more variable.

Biological controls: possible and potentials good BUT beekeepers/dove hunters/others oppose controls; *Tamarix* honey gets higher prices in Texas but lower prices in Utah; *Tamarix* provides browse for some animal species. The plant also has aesthetic value in Utah where 5-gallon size nursery plants sell for $18. Biological controls, if not regulated, could effect home landscaping.

Watts (1977) collected 159 insect species and 1 mite from New Mexico *Tamarix* but with little evidence of plant damage. Two alien species, leafhopper (*Opsius stactogalus*) and scale (*Chionaspis etrusca*), often abundant on damaged plants. In native range, 115 insect species and 4 mites known to attack plant, a few may be candidates for biological controls. Introduced insect controls could be aimed at 50% reduction of *Tamarix* stands, then effects upon dove hunting/honey production evaluated. A 50-80% reduction would allow reestablishment of much native vegetation, conserve large amounts of water, cause little harm to beneficial uses of the plant.

Bill Neill: Start all *Tamarix* control with larger trees on higher elevations, those likely to survive floods/reseed canyon floors; younger trees/saplings at lower elevations can be ignored, they will be eventually be washed away. Control at desert springs, once accomplished, relatively permanent. Control on flood-prone river courses extremely difficult. Grub individual plants; cut established plants to within 2-inches of soil line. Continually monitor in late winter (before flowering); remove new seedlings. Late spring (Apr. to Jun.) only practical time to search for *Tamarix* seedlings when mixed with other vegetation/plants easily distinguished by flowers. Replacing *Tamarix* with native species may lessen/delay recolonization; *Tamarix* seems to occupy areas not used by native plants (unoccupied niche); after *Tamarix* invades areas, it alters habitat so other native species may not survive. Habitat alteration, favorable to *Tamarix*, includes generation of sandy soils, frequent flooding/drought, salty soil surface (shed *Tamarix* leaves produce salty soils).

Herbicides: foliage sprays may kill top-growth but plants readily root-sprout. Basal/stump Silvex application gave 60% control but Silvex now banned. Root plow-applied herbicides (picloram, dicamba at 6-7 kg/hectare) give 90-97% control for 4 years. Less successful applications usually show plant girth not completely cut/plant not cut close enough to ground.

During spring months, treated stumps may send up several stems before dying; delay follow-up inspections 3-4 months to 1 year post-treatment to detect still-active stumps. *Tamarix* trees on floodplains may be more difficult to kill, require 3= treatments. Winter (tree is dormant) best time for herbicide applications; spring least desirable (sap flow upwards).

Treat stumps with picloram (Tordon RTU, Amdon, Borlin, Grazon) or triclopyr (Garlon 3A, Dowco 233) in minutes of cutting or would healing lessens effect; repeat as needed.

Tordon: ingredients in Tordon, 2,4-D picloram, resemble plant hormones, not especially toxic to animal life; long-term exposure may be carcinogenic/mutagenic. Tordon is a Restricted Use chemical with a long half-life (up to 3-years) and the reason it is restricted is because it is easily translocated to nearby non-target (i.e. mesquite) species. Picloram may be applied as a liquid spray or pellet by ground/aerial application; often mixed with other herbicides (particularly 2,4-D and marketed under brand names: Tordon and Amdon). Picloram has low toxicity to mammals/birds, moderate toxicity to fish; is more persistent in environment than many herbicides, lasting from several months to several years, depending on conditions. Picloram has low potential for accumulating in animal tissue; if ingested, is rapidly excreted. Livestock moved off picloram-treated area excrete picloram in urine (plant damage) up to 7-days. Picloram is Restricted Use because of its potential for damaging non-target plants by run-off/leaching, not because of known/suspected health risks (EPA, 1982).

Garlon: Garlon is short-lived but more toxic to mammals than tordon; it has a half-life of only 30-days. Do not graze livestock on Garlon-treated areas for up to 1-year. NPS favors Garlon over Tordon because it is not a Restricted Use chemical and of restrictions that will come for Tordon; Garlon allows plant to resprout. Garlon 3A showed very poor success in at least 1 Los Angeles application.

RESTORATIONS

In Arizona, the following plants have been shown to share dominance with *Tamarix* (tolerate like conditions):

DENSE TAMARIX THICKETS ALONG PUERCO RIVER AND NINEMILE WASH, AZ

coyote willow (*Salix exigua*)
sacaton (*Sporobolus airoides*)
Fremont cottonwood (*Populus fremontii*)

ALONG SMALLER STREAM COURSES

salt-bush (*Atriplex jonesii, A. confertifolia*)
iodine bush (*Allenrolfea occidentalis*)
burroweed (*Happlopappus drummondii*)
black greasewood (*Sarcobatus vermiculatus*)
sand dropseed (*Sporobolus cryptandrus*)
ring muhly (*Muhlenbergia pungens*)
big reed (*Calamovilfa gigantea*)
Indian rice grass (*Oryzopsis hymenoides*)
dune vetch (*Parryella filifolia*)
snake weed (*Gutierrezia sarothrae, G. lucida*)
rubber rabbitbrush (*Chrysothamnus nauseosus*)
Oxytenia acerosa

TABLE 1. Available Herbicides for Tamarisk.

	Garlon 3A Dow Chemical	Tordon RTU Dow Chemical	Tordon 101R Dow Chemical	Tordon 101 Dow Chemical	Arsenal American Cyanamide
Cost:	$53.80/gal.	$26/gal.	$17.65/gal.	$16.85/gal. (diluted 1:1)	$160-$190 gal.
Ingredient:	Picolinic acid (Tryclopyr)	Picloram	Picloram	Picloram	Imidazolinone
LD-50	713 mg/kg	8200 mg/kg	8200 mg/kg	8200 mg/kg	>5000 mg/kg
Restricted Use Chemical:	NO	YES	YES	YES	NO
Persistence:	ca. 2-weeks	Soil residual	Soil residual	Soil residual	Soil, 7 mo. or less
Anti-Freeze: Additive	Methanol	Ethylene glycol	Ethylene glycol	None	
Folial Spray:	YES	YES	YES	YES	YES
Injection:	YES	YES			
Bark Treatment:	YES	YES	YES	YES	YES
Effectiveness (Established plants)	77%	95%+	95%+	95%+	Said to be good
Other:	No grazing of area 1-yr.; most effec. on root suckering plants.				Mix with Roundup to lessen soil residual.
Fish Toxic:	Low				Yes, low
Grass Injury:	Not at low concentrations	Low	Low	Low	YES

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Neill, B. 4900 Glenview, Anaheim, CA 92807; home 714/779-2099; work 714/528-7201, extension 2423; sends out Tamarisk Newsletter; contracts out for controlling Tamarix in NPS/other areas but advertises for/uses volunteers; gives advice on control; mostly uses Tordon. Works for Union Oil Company, is not a professional Tamarix remover.

Rorabaugh, J., Bureau of Reclamation, Yuma, AZ; FTS 764-6658; 602/726-2658; Starting a program in conjunction with USDA/ARS to explore biological controls.

Sanchez, P., Chief Ranger Haleakala National Park, HI - 808/572-9306/9026.

Turner, R.M., USGS, 300 W. Congress St., Tucson, AZ 85701; 762-6821.

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